PREFACE

Sagebrush-grass rangelands have been the subject of considerable research during the past half century. The resulting literature is extensive. Harniss and others (1981) have published a bibliography with 1,250 citations. Tisdale and Hironaka (1981) have authored a review of ecological literature on sagebrush-grass.

Most managers and users of rangelands have neither ready access to the literature nor the time necessary to search it.

This current publication is not a comprehensive review of the literature. It is a distillation of some of the most important information that may be helpful in planning and decisionmaking. Our purpose is to provide sagebrush-grass rangeland managers and users with a reference or guide to research results. Those wanting more detailed information can follow up on the literature citations here or in the aforementioned bibliography or review of ecological literature.

Some of the more recent research has shown that sagebrush-grass ecology is more varied and complex than we once thought. Therefore, we have devoted considerable space to taxonomy and classification of sagebrush ecosystems. These sections can be useful working materials for resource managers.

Partly because of the ecological variation within the broad sagebrush-grass rangeland area, and partly because past research has been concentrated more in some parts of the West than in others, it is not possible to apply all research results to all sagebrush-grass lands. Good judgment and understanding the several sagebrush ecosystems are necessary in extending the results of any research findings.

We hope that managers and users of western rangelands find this to be a useful reference.

RESEARCH SUMMARY

Sagebrush-grass vegetation makes up one of the largest range ecosystems in the Western United States. Much of it was abused during early settlement of the West, and much of it is still far below its potential in livestock forage production, wildlife habitat, and environmental quality. Sagebrush-grass rangelands have been the subject of considerable research during the past half century. The resulting literature is extensive—with over 1,250 citations. Most managers and users of rangelands cannot study and digest all this material for themselves. This paper is a distillation of some of the most important information available that may be helpful in planning and decisionmaking. It is intended to be a manager's reference and guide to research results. It includes summaries of the latest information on sagebrush taxonomy and classification of sagebrush ecosystems as well as on methods of rehabilitating, converting, and managing these ecosystems.

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Managing Intermountain Rangelands —Sagebrush-Grass Ranges

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INTRODUCTION

The Resource

Sagebrush includes the species, all woody, of subgenus *Tridentatae* of the genus *Artemisia*. Sagebrush-grass vegetation occupies a substantial portion of the western range. It extends over much of Utah, Nevada, southern Idaho, eastern Oregon, western Montana, Wyoming, and Colorado, as well as smaller areas in Washington, California, Arizona, and New Mexico (Tisdale and others 1969). Estimates of total acreage vary from some 95 million acres (38 million ha) (USDA Forest Service 1936 and 1972) to 270 million acres (109 million ha) (Beetle 1960). Even if the lower estimate is accepted as reasonably accurate, sagebrush-grass vegetation is still one of the largest—if not the largest—range ecosystem in the western United States.

Native sagebrush-grass vegetation is dominated by woody species of *Artemisia* with an understory of perennial grasses and forbs. However, vegetal cover is usually not continuous and considerable bare ground is often exposed. Sagebrush generally occurs at elevations from 5,000 to 7,000 ft (1 525 to 2 140 m), but some species grow at elevations as low as 1,600 ft (490 m) and others as high as 11,500 ft (3 500 m). Dwarf sagebrushes are mostly confined to the shallow soils, whereas the tall sagebrushes generally occur on the deeper soils and comprise the greatest area. Other important shrubs are rabbitbrush (*Chrysothamnus*), bitterbrush (*Purshia*), horsebrush (*Tetradymia*), chokecherry (*Prunus*), serviceberry (*Amelanchier*), hopsage (*Grayia*), Mormon tea (*Ephedra*), wild currant (*Ribes*), mountain mahogany (*Cercocarpus*), and snowberry (*Symphoricarpos*).

Although a large number of herbaceous species are present throughout the sagebrush ecosystem, a relatively few species comprise the bulk of the biomass. Principal grasses are wheatgrasses (*Agropyron*), fescues (*Festuca*), bluegrasses (*Poa*), bromegrasses (*Bromus*), junegrass (*Koeleria*), needlegrasses (*Stipa*), squirreltail (*Sitanion*), ricegrass (*Oryzopsis*), and wildrye (*Elymus*). Forbs are present in a much greater variety than grasses, but their distribution is much less uniform. However, one species, arrowleaf balsamroot (*Balsamorhiza sagittata*), is very widespread and often abundant. Other common forbs present in varying quantities are yarrow (*Achillea*), pussytoes (*Antennaria*), locoweed (*Astragalus*), segolily (*Calochortus*), hawksbeard (*Crepis*), [illegible]
[illegible]

Problems

Unfortunately, much of the valuable sagebrush resource was depleted during the early years of western settlement by abusive grazing, by unregulated and recurrent fires, and by cultivation and abandonment of marginal lands. Despite several decades of "improved" management, the sagebrush ecosystem is still far below its potential in livestock forage production, wildlife habitat, and environmental quality (USDA Forest Service 1972).

A primary problem is the increase in numbers and size of sagebrush and other low value shrubs that have accompanied the reduction in perennial grasses and forbs. Not only is this a direct loss of forage, but resulting stands of sagebrush are frequently so dense that they form a barrier to livestock movements. Sheep can make their way through such stands only with difficulty, wool is pulled from fleeces, and lambs are lost through straying. Even when livestock force their way into thick sagebrush stands, they are often unable to reach more than half of the palatable grasses and forbs. Because of its long life and ability to compete with perennial herbs for soil moisture and nutrients, sagebrush in dense stands is a serious obstacle to range improvement through grazing management or seeding of desirable species (Blaisdell 1953).

In other extensive areas, destruction of sagebrush-grass vegetation by fire, heavy grazing, or cultivation has allowed conversion to annuals, particularly cheatgrass (*Bromus tectorum*). Although ranges dominated by this exotic may provide good spring forage, it is not dependable because of wide year-to-year fluctuations in yield. Also, cheatgrass is a serious fire hazard and allows invasion of poisonous or other weeds such as halogeton (*Halogeton glomeratus*), Russian thistle (*Salsola kali*), tumble mustard (*Sisymbrium altissimum*), medusahead (*Taeniatherum asperum*), bur buttercup (*Ranunculus testiculatus*), sunflower (*Helianthus annuus*), tarweed (*Madia*), prickly lettuce (*Lactuca serriola*), and stickseed (*Lappula occidentalis*).

Although accelerated erosion has often accompanied vegetal deterioration, severe runoff and erosion has not occurred on many areas now occupied by thick stands of sagebrush and annuals. However, serious problems have been created by flooding, especially in parts of the Great Basin where deep channels have been cut in many small streams. Often aquatic habitat has been seriously damaged, and the normal riparian vegetation has been modified or destroyed as a result of a lowered water table and heavy grazing pressure. Secondary consequences of range deterioration, then, are lowered grazing capacity for livestock, reduction in populations of fish and wildlife, and damage to environmental quality, especially esthetics.

Obviously, the solution is restoration of desirable vegetation through direct improvement and/or grazing management practices. The task will not be easy. Advanced deterioration of vegetation and soil will be difficult to correct, and varinbility of the ecosystem will complicate the development of workable prescriptions. Sagebrush-grass range, which was once thought to be fairly uniform, is now known to contain numerous subunits of vegetation determined by differences in climate, soil, and topography. These communities are characterized by specific kinds of sagebrush (species, subspecies, varieties, ecotypes, forms, strains, and so forth) in combination with complex mixtures of other shrubs, grasses, and forbs. Sagebrush can be valuable or pestiferous in different degrees depending on inherent qualities or location; consequently, sagebrush systematics must be addressed to identify taxa that require peculiar management strategies (McArthur 1979). Likewise, sound classification of natural landscape units based on potential and on an understanding of ecosystem dynamics is needed to facilitate management decisions for sagebrush-grass ranges (Tisdale and others 1969). Knowledge of range condition or relative health of the vegetation and soil and whether it is getting better or worse (trend) is essential for planning livestock grazing programs or managing other land uses (Pechanec and Stewart 1949).

TAXONOMY OF SAGEBRUSH

Classification

The North American sagebrushes comprise subgenus *Tridentatae* (Rydb.) E. D. McArthur of the genus *Artemisia* L. Although its taxonomic limits remain in some dispute, *Tridentatae* is a natural grouping of species based on habit, morphology, anatomy, chemistry, and cytology (McArthur 1979; McArthur and others 1981). Incidentally, it seems reasonable to follow McArthur's suggestion of using "sagebrush" when referring to the *Tridentatae* group of *Artemisia* and "sage" for the non-*Tridentatae*.

In 1814, Pursh described the first *Tridentatae* species, *A. cana* Pursh, from material collected in 1804 by explorers Lewis and Clark. Nuttall described two widespread species, *A. tridentata* Nutt. and *A. arbuscula* Nutt., in the early 1840's. Rydberg (1916) developed a systematic treatment of *Artemisia*, and his framework has been used by subsequent workers, especially Hall and Clements (1923), Ward (1953), Beetle (1960), and Beetle and Young (1965). The relations between the various species and subspecific taxa are shown in table 1.

An additional taxon, *A. tridentata* ssp. *vaseyana* form "*xericensis*," was suggested by Winward (1970). However, he more recently proposed that this variant (tentatively referred to as type "X") be given higher status as a subspecies of *A. tridentata* (Winward 1975). Although critical evaluation of sagebrush taxonomy should continue, it appears that Beetle's system is generally adequate for classification of most sagebrush entities.

Table 1.—Development of subgenus *Tridentatae*[1] of genus *Artemisia* (from McArthur 1979)

Beetle (1960) Beetle and Young (1965)	Ward (1953)	Hall and Clements (1923)	Rydberg (1916)
A. arbuscula Nutt. ssp. *arbuscula*	*A. arbuscula* ssp. *arbuscula*	*A. tridentata* ssp. *arbuscula* (Nutt.) H&C	*A. arbuscula*
A. arbuscula Nutt. ssp. *thermopola* Beetle	—	—	—
A. argillosa Beetle	—	—	—
A. cana Pursh ssp. *cana*	*A. cana* ssp. *cana*	*A. cana*	*A. cana*
A. cana Pursh ssp. *bolanderi* (Gray) Ward	*A. cana* ssp. *bolanderi*	*A. tridentata* ssp. *bolanderi* (Gray) H&C	*A. bolanderi* Gray
A. cana Pursh ssp. *viscidula* (Osterhout) Beetle	*A. cana* ssp. *cana*	*A. cana*	*A. cana*
A. longiloba (Osterhout) Beetle	*A. spiciformis* var. *longiloba* Osterhout	—	—
A. nova Nelson	*A. arbuscula* ssp. *nova* (Nelson) Ward	*A. tridentata* ssp. *nova* (Nelson) H&C	*A. nova*
A. rothrockii Gray	*A. rothrockii*	*A. tridentata* ssp. *rothrockii* (Gray) H&C	*A. rothrockii*
A. tridentata Nutt. ssp. *tridentata*	*A. tridentata* ssp. *tridentata*	*A. tridentata* ssp. *typica*	*A. tridentata*
A. tridentata Nutt. ssp. tridentata	*A. tridentata* ssp. *tridentata*	*A. tridentata* ssp. *typica*	*A. angusta* Rydb.
A. tridentata Nutt. ssp. *tridentata* f. *parishii* (Gray) Beetle	*A. tridentata* ssp. *parishii* (Gray) H&C	*A. tridentata* ssp. *parishii*	*A. parishii* Gray
A. tridentata Nutt. ssp. *vaseyana* (Rydb.) Beetle	*A. tridentata* ssp. *tridentata*	*A. tridentata* ssp. *rothrockii* (Gray) H&C	*A. vaseyana* Rydb.
A. tridentata Nutt. ssp. *vaseyana* (Rydb.) Beetle f. *spiciformis* (Osterhout) Beetle	—	*A. tridentata* ssp. *rothrockii* (Gray) H&C	*A. spiciformis* Osterhout
A. tridentata Nutt. ssp. *wyomingensis* Beetle and Young	—	—	—
A. tripartita Rydb. *tripartita*	*A. tripartita*	*A. tridentata* ssp. *trifidia* (Nutt.) H&C	*A. tripartita*
A. tripartita Rydb. ssp. *rupicola* Beetle	—	—	—
A. pygmaea Gray	*A. pygmaea*	*A. pygmaea*	TRIDENTATAE[2]
A. rigida (Nutt.) Gray	*A. rigida*	*A. rigida*	*A. pygmaea* PYGMAEAE
A. bigelovii Gray	*A. bigelovii*	*A. bigelovii*	*A. rigida* RIGIDAE
			A. bigelovii ABROTANUM

[1]Rydberg (1916) and Beetle (1960) used subgenus Tridentatae whereas Hall and Clements (1923) and Ward (1953) referred to North American members of the subgenus Seriphidium.
[2]Some of Beetle's (1960) Tridentatae species were assigned to other sections by earlier workers.

Identification

Fairly complete keys to the taxa of *Tridentatae* were prepared by Beetle (1960) and McArthur and others (1979). Also, useful keys to the *Artemisia tridentata* complex in Idaho and in Oregon were developed by Winward and Tisdale (1977) and Winward (1980), respectively. Because it is the most recent and comprehensive, the McArthur and others key is reproduced here in figure 1; however, the other three are also useful and are included in the appendix.

Based on their own research, as well as a thorough review of the literature, McArthur and others (1979) have developed descriptions of the most important sagebrush taxa. Summaries, emphasizing characteristics and distribution, follow in alphabetical order.

ARTEMISIA ARBUSCULA NUTT. (LOW SAGEBRUSH)

Low sagebrush is a spreading, irregularly branched shrub up to 20 inches (5 dm) high. The slender erect twigs are densely canescent, but may become nearly glabrous and thus darker green in late summer. The plant layers infrequently. Leaves are broadly cuneate or fan-shaped, 0.2 to 0.6 inch (0.5 to 1.5 cm) long and 0.1 to 0.4 inch (0.3 to 1 cm) wide, and usually have three (occasionally four to five) teeth or clefts at the apex. Leaves on the upper part of the flowering shoots may become entire. Flower heads are grouped into elongated, narrow racemes. The heads usually contain 5 to 11 disc flowers with corollas 0.12 to 0.16 inch (3 to 4 mm) long. The 10 to 15 involucral bracts are canescent. Flowering occurs from August to September, depending upon strain and elevation. Seed ripens in October and November.

1a. Heads with both ray (marginal) flowers and disc flowers; plants subshrubs or shrubs.

2a. Plants subshrubs; leaves 2 or 3 times pinnately parted, silky-canescent; widely distributed through western North America, Siberia, northern Asia, and Europe ..... *A. frigida*
(fringed sagebrush)

2b. Plants shrubs; leaves not as above.

3a. Branches spinescent; leaves 3 to 5 palmately parted with segments three-lobed, white tomentose, deciduous; occurs on dry, saline plains and hills from northwestern Montana west to eastern Oregon and south to California, Arizona, and New Mexico ..... *A. spinescens*
(bud sagebrush)

3b. Branches not spinescent; leaves not as above.

4a. Leaves filiform, entire or ternately divided into filiform segments, silvery-white canescent; heads with 2 to 3 ray flowers and 1 to 6 disc flowers; occurs mostly in sandy soil from Nevada east to western Nebraska and south to Texas, Arizona, and Chihuahua ..... *A. filifolia*
(sand sagebrush)

4b. Leaves narrowly cuneate, mostly finely tridentate, silvery-canescent; heads smaller with 0 to 2 ray flowers and 1 to 3 disc flowers; occurs in canyons, gravelly draws, and dry flats from western Texas to California ..... *A. bigelovii*
(Bigelow sagebrush)

1b. Heads with disc flowers only; plants shrubs.

5a. Plants up to 5 dm high.

6a. Plants dwarf, less than 2 dm high.

7a. Plants depressed, cushionlike shrubs; leaves 2 to 8 mm long, pinnately divided into 3 to 11 lobes; limited to calcareous desert soils, central and western Utah, central and eastern Nevada, and northern Arizona ..... *A. pygmaea*
(pigmy sagebrush)

7b. Plants with decumbent, frequently layering branches; leaves often 3 cm long, deeply cleft into 3 linear lobes; rocky knolls from 2 430 to 2 740 m in central and southeastern Wyoming to southern Oregon ..... *A. tripartita* ssp. *rupicola*
(Wyoming threetip sagebrush)

6b. Plants low from 2 to 5 dm high (but may be less).

8a. Heads axillary and sessile, generally all surpassed by their subtending leaves; leaves deeply divided into 3 to 5 narrowly linear lobes; deciduous ..... *A. rigida*
(stiff sagebrush)

8b. Heads usually in branched racemose panicles or if spikelike, then subtending leaves do not surpass heads; leaves three- to five-toothed or lobed, cuneate to fan-shaped, persistent.

9a. Leaves broadly cuneate, deeply three-lobed involucre broadly companulate; flower heads 3 to 5 mm broad with 6 to 11 disc flowers; blooming begins in mid-June; seeds 2.5 mm long, ripening in August; adapted to heavy, highly impermeable, saline soils from 1 800 to 2 450 m from southwestern Montana to northwestern Colorado, Utah, Nevada, Idaho, and Oregon ..... *A. longiloba*
(alkali sagebrush)

9b. Leaves cuneate to broadly cuneate or fan-shaped, three- to five-toothed or cleft; involucre narrowly campanulate; flower heads and seed smaller than above; blooming normally occurring later than July; seed ripen late September and October.

10a. Leaves cuneate, three-toothed (upper leaves may be entire), viscid; heads arranged in narrow spikelike panicles; disc flowers 3 to 5 per head; corollas 1.8 to 3 mm long; involucral bracts glabrous or nearly so; plants usually dark green with persistent red-brown inflorescent stalks; occurs on dry, shallow, rocky soil between 1 500 and 2 400 m in most western States ..... *A. nova*
(black sagebrush)

10b. Leaves broadly cuneate or fan-shaped, three- to five-toothed or cleft (upper leaves may be entire), not viscid; heads arranged in narrow racemose panicles; disc flowers 5 to 11 per head; corollas 3 to 4 mm long; involucral bracts canescent; plant usually lighter in color than above; distribution similar to *A. nova* but offset to the northwest, usually found at somewhat higher elevations in more moist habitats than *A. nova* ..... *A. arbuscula*
(low sagebrush)

Figure 1.--Key to species and subspecies of *Artemisia* (from McArthur and others 1979).

5b. Plants usually over 5 dm high (14b and 17b provide most exceptions to 5 dm height).

11a. Leaves silvery-canescent, linear to linear-oblanceolate, mostly entire (occasionally with a few irregular teeth), or leaves deeply divided into 3 or more linear or linear-oblanceolate lobes.

12a. Leaves entire or occasionally with 1 or 2 irregular teeth or lobes ..... *A. cana* (silver sagebrush)

13a. Leaves 2 to 8 cm long, 1 to 10 mm wide, densely silky-canescent; heads arranged into dense leafy panicles; occurs mostly east of the Continental Divide from southern Canada to northern Colorado ..... *A. cana* ssp. *cana* (silver sagebrush)

13b. Leaves smaller than above (up to 7 cm long, 1 to 5 mm wide) and often crowded into dark-green clusters; heads arranged into dense, short raceme or spikelike inflorescences; occurs mostly west of the Continental Divide from southwestern corner of Montana to Arizona and New Mexico ..... *A. cana* ssp. *viscidula* (mountain silver sagebrush)

12b. Leaves typically deeply divided into 3 linear or narrowly lanceolate lobes which in turn may be three-cleft ..... *A. tripartita* (threetip sagebrush)

14a. Plants freely branching shrubs up to 2 m; leaves 1.5 to 4 cm long, deeply divided into 3 linear lobes, each less than 1 mm wide; occurs on dry, well-drained soils from 900 to 1 800 m from British Columbia south to northern Nevada, northern Utah, and western Montana ..... *A. tripartita* ssp. *tripartita* (tall threetip sagebrush)

14b. Plants dwarf shrubs with decumbent, often layering branches; leaves up to 3 cm long, deeply divided into linear lobes 1 mm or more wide; occurs on rocky knolls from 2 430 to 2 740 m in central and southeastern Wyoming to southern Oregon ..... *A. tripartita* ssp. *rupicola* (Wyoming threetip sagebrush)

11b. Leaves not silvery-canescent, narrowly lanceolate to broadly cuneate or fan-shaped, typically three-toothed or lobed (upper leaves may be entire).

15a. Plants low-growing, flat-topped shrubs up to 8 dm high; leaves somewhat viscid; heads occurring singly or occasionally up to 3 arranged in short interrupted spike or racemelike inflorescences; heads large with up to 20 disc flowers each; occurs in high mountainous areas of central Colorado, western Wyoming, Utah, central Sierras of California, and Carson Range of Nevada ..... *A. rothrockii* (timberline sagebrush)

15b. Plants ranging from dwarf to tall, arborescent forms up to 4.5 m; leaves not viscid; inflorescences of numerous heads arranged into leafy panicles; heads smaller with 3 to 8 disc flowers; most widespread and common shrub of western North America ..... *A. tridentata* (big sagebrush)

16a. Plants uneven-topped shrubs with flowering stalks arising throughout the crown; leaves narrowly lanceolate to cuneate; odor of crushed leaves pungent.

17a. Mature plants often arborescent (with single trunkline main stem), usually from 1 to 2 m but in some forms up to 4.5 high; leaves narrowly lanceolate with margins not curving outward; average persistent 5.6 times its width; blooming starts in late August or September; odor strongly pungent; normally occurs below 2 100 m in dry deep, well-drained soils on plains, valleys, and foothills ..... *A. tridentata* ssp. *tridentata* (basin big sagebrush)

17b. Mature plants with several main branches usually less than 1 m high; leaves narrowly cuneate to cuneate with margins curved outward; average persistent leaf length is 3.1 times its width; blooming starts in late July or August, odor pungent; occurs on dry, shallow, gravelly soil from 1 500 to 2 100 m ..... *A. tridentata* ssp. *wyomingensis* (Wyoming big sagebrush)

16b. Plants usually even-topped shrubs with flower stalks arising from upper crown portions; leaves broadly cuneate to spatulate; average persistent leaf length is 4.0 times its width; blooming may begin in July; odor slightly pungent to pleasantly mintlike; occurs from 1 400 to 3 000 m in deep well-drained soils ..... *A. tridentata* ssp. *vaseyana* (mountain big sagebrush)

A dwarf form of *A. arbuscula* occurs in the Stanley Basin area of Idaho, the Jackson Hole, Wyo., area, and perhaps in other locations. Beetle (1960) named this form *A. arbuscula* ssp. *thermopola*—hotsprings sagebrush. He speculated that this form arose as the result of hybridization between typical *A. arbuscula* and *A. tripartita*.

Low sagebrush grows on dry, sterile, rocky, often alkaline soils between 2,300 and 11,500 ft (700 and 3 500 m) covering approximately 39,100 mi^2 (10.1 million ha) in 11 western States. In the warmer, drier parts of its range, particularly in Nevada, it may grow well into the mountains above 9,800 ft (3 000 m). In some areas, low sagebrush occurs on disjunct low and high elevation bands.

Low sagebrush ranges from southern Colorado to western Montana and west throughout Utah and Idaho to northern California, Oregon, and Washington. Normally its sites are more rocky than those with big sagebrush, and are wetter in the spring and drier in the fall.

Low sagebrush and black sagebrush sometimes occur in intermixed stands. In areas where the distribution of these two species overlaps, low sagebrush is usually found in the more moist habitats or at slightly higher elevations than black sagebrush.

ARTEMISIA ARGILLOSA BEETLE (COALTOWN SAGEBRUSH)

Coaltown sagebrush is an erect shrub 20 to 32 inches (5 to 8 dm) tall. Leaves are up to 1.6 inches (4 cm) long, deeply trifid, resembling those of *A. tripartita*, but commonly longer with wider lobes. Flower heads appear in July, bloom in August, and seed ripens by October. This species has a limited distribution of about 1 mi^2 (260 ha) in Jackson County, Colo., where it occurs on strongly alkaline soil (Beetle 1960). It is, however, abundant on this site where it is associated with Wyoming big sagebrush and alkali sagebrush.

ARTEMISIA BIGELOVII GRAY (BIGELOW SAGEBRUSH)

Bigelow sagebrush is a low shrub 8 to 16 inches (2 to 4 dm) high with numerous spreading branches. The flowering stems are slender and erect and bear inflorescences that are long, narrow panicles with short, recurved branches. New growth is covered with a silvery-canescent pubescence. The leaves of vegetative branches are similar to those of big sagebrush. They are narrowly cuneate, 0.4 to 0.8 inch (1 to 2 cm) long, 0.08 to 0.2 inch (2 to 5 mm) wide, and normally tridentate, but may have extra tips. The odor of crushed leaves is mild like that of mountain big sagebrush (*A. tridentata* ssp. *vaseyana*). The heads are arranged into elongated, narrow panicles and normally contain 1, but occasionally 0 to 2, ray flowers and 1 to 3, usually 2, disc flowers. The turbinate involucre consists of 8 to 12 short, densely tomentose bracts 0.08 to 0.16 inch (2 to 4 mm) long and 0.06 to 0.1 inch (1.5 to 2,5 mm) broad. Flowering occurs from August to October.

Bigelow sagebrush closely resembles and is often mistaken for low forms of big sagebrush produced by overgrazing and burning. In contrast to big sagebrush, however, it has ray flowers. Furthermore, lobes of *A. bigelovii*'s vegetative leaves are always more shallow and more sharply dentate than those of big sagebrush.

Bigelow sagebrush has a more southerly distribution than other sagebrushes, and is one of the most drought-resistant. It occurs over approximately 34,000 mi^2 (8.8 million ha) through western Texas, southern Colorado, New Mexico, Arizona, Utah, Nevada, and California in canyons, gravelly draws, and dry flats from 3,000 to 7,900 ft (900 to 2 400 m).

ARTEMISIA CANA PURSH (SILVER SAGEBRUSH)

Silver sagebrush is an erect, freely branched, rounded shrub up to 5 ft (1.5 m) tall. Older branches have dark brown, fibrous bark while younger branches are covered with a dense white to yellowish-green tomentum. Leaves on the vegetative branches are 0.04 to 0.4 inch (1 to 10 mm) wide and 0.8 to 3.2 inches (2 to 8 cm) long, linear to linear-oblanceolate, entire or occasionally with 1 or 2 ephemeral leaves with irregular teeth or lobes, silver-canescent becoming slightly viscid with age. Leaves on the flowering stems are similar, but they may be slightly smaller, especially on the upper parts of the stems. The foliage emits a mild to pungent aromatic odor when crushed. Numerous heads are arranged into dense, narrow, leafy panicles, sometimes reduced to raceme or spikelike inflorescence. Each head contains 4 to 20 disc flowers. Ray flowers are lacking. Achenes are granuliferous. Blooming occurs during August and September.

Silver sagebrush occurs over approximately 53,200 mi^2 (13.8 million ha) from British Columbia to Saskatchewan, south to Nebraska, Colorado, and New Mexico, and west to Oregon and California on valleys, plains, foothills, and mountains up to 10,000 ft (3 050 m).

Artemisia cana ssp. *cana* (silver sagebrush) is an erect, rounded, freely branched shrub up to 5 ft (1.5 m) tall. It layers whenever conditions are suitable. This subspecies may spread rapidly, particularly after burning, by rootsprouting and by rhizomes. Leaves of the vegetative branches are linear-oblanceolate, entire or rarely with one or two irregular teeth or lobes, 0.04 to 0.4 inch (1 to 10 mm) wide, 0.8 to 3.2 inches (2 to 8 cm) long, and are densely silky-canescent. Crushed foliage emits a pungent turpentine odor. Flower heads are usually arranged into dense, leafy panicles and may contain from 5 to 20 disc flowers. Blooming occurs during September, and the seeds ripen during October and November. It occurs from southern Canada southward, but mostly east of the Continental Divide, through Montana, the Dakotas, Wyoming, western Nebraska, and northern Colorado.

Artemisia cana ssp. *viscidula* (mountain silver sagebrush) is an erect shrub that readily layers. It usually is not more than 3.3 ft (1 m) tall. Leaves on the vegetative branches are 0.04 to 0.2 inch (1 to 5 mm) wide, up to 2.8 inches (7 cm) long, and are often crowded in dark green clusters. The leaves typically are simple and entire, but occasionally ephemeral leaves are variously toothed or lobed. This subspecies varies in appearance, but is always darker green than mountain big sagebrush with which it is often growing. Mountain silver sagebrush is distinguished from subspecies *cana* by its smaller, darker green leaves, its lower stature, and more western distribution. Flower heads are arranged into dense, short raceme or spikelike inflorescences 0.4 to 1.2 inches (1 to 3 cm) long. Each head contains from 4 to 15 disc flowers. Flowers bloom during August and September. Seed matures during October and November. Mountain silver sagebrush occurs in mountainous regions around 6,900 ft (2 100 m) and above. It is usually found along streamsides and in areas of heavy, lingering snowpack from the southwest corner of Montana, south along the Continental Divide to New Mexico, and west to Arizona, Nevada, Utah, and Idaho.

Artemisia cana ssp. *bolanderi* (Bolander silver sagebrush) is a subspecies that occurs in extreme western Nevada and in

California and Oregon. It is similar to but more canescent than ssp. *viscidula* and grows on internally drained, usually more alkaline soils than *viscidula*.

ARTEMISIA LONGILOBA (OSTERHOUT) BEETLE (ALKALI SAGEBRUSH)

Alkali sagebrush is a low shrub up to 18 inches (4.5 dm) tall. It has lax, spreading stems that frequently layer. The bark is dark brown to black on the older stems. The whole plant has a dark gray-green appearance. Leaves on the vegetative stems are broadly cuneate, up to 0.8 inch (2 cm) long, and are deeply three-lobed. Leaves of the flowering stems are similar but smaller on the upper part of the plants. Crushed foliage emits a pungent odor similar to that of camphor in the spring, and to hydraulic fluid in the fall.

Alkali sagebrush is readily distinguished from other low sagebrushes by its large heads and early blooming period. Its heads contain 6 to 11 disc flowers and are 0.12 to 0.2 inch (3 to 5 mm) broad as opposed to 0.12 inch (3 mm) or less for other low species. Alkali sagebrush blooms approximately a month earlier than other low sagebrushes. It flowers during mid-June to mid-July and its seed ripens in late July or early August. This species has sometimes been confused with *A. cana* because of its large heads, with *A. tridentata* because of its broadly cuneate, three-lobed leaves, and with *A. arbuscula* because of its dwarf size.

Unlike other sagebrushes, alkali sagebrush characteristically grows in heavy, highly impermeable soils derived from shales, but it also is frequently found on the lighter, limey soils. It occurs between 5,900 and 8,000 ft (1 800 and 2 450 m) in elevation over 5,120 mi^2 (1.3 million ha) along the foothills of the ranges forming the Continental Divide from southwestern Montana, south through Wyoming to northwestern Colorado, and scattered westward to Utah, Nevada, Idaho, and Oregon.

ARTEMISIA NOVA NELSON (BLACK SAGEBRUSH)

Black sagebrush is a small, spreading, aromatic shrub 6 to 18 inches (1.5 to 4.5 dm) tall with a dull grayish-tomentose vestiture that causes most populations to appear darker than big sagebrush and low sagebrush. However, some forms might be as light in color as *A. tridentata* or *A. arbuscula*. Numerous erect branches arise from a spreading base, but this shrub has not been observed to layer or stump sprout. Typical leaves are evergreen, cuneate, viscid from a glandular pubescence, 0.2 to 0.8 inch (0.5 to 2 cm) long, 0.08 to 0.32 inch (2 to 8 mm) wide, and three-toothed at the apex. The uppermost leaves, particularly on the flowering stems, may be entire. Flower heads are grouped into tall, narrow panieles that extend above the herbage. The inflorescence stalks are red-brown and persistent. The heads usually contain from three to five disc flowers with corollas 0.07 to 0.12 inch (1.8 to 3 mm) long. The 8 to 12 involueral bracts are greenish-yellow and nearly glabrous. Flowering occurs from August to mid-September, and seeds mature in October and November.

The principal difference between black sagebrush and low sagebrush is that the latter has 5 to 11 flowers per head, 10 to 15 canescent involucral bracts, and is light in color. Black sagebrush has fewer flowers per head (3 to 5), 8 to 12 glabrous involucral bracts, and is usually darker in color. Also, the flower stalks of black sagebrush are denser, much darker, and more persistent than those of low sagebrush.

Black sagebrush covers approximately 43,300 mi^2 (11.2 million ha) in the 11 western States. It is most abundant at elevations from 5,000 to 8,000 ft (1 500 to 2 400 m) and normally grows on drier, shallower stony soil than basin or mountain big sagebrush. It has an affinity for calcareous soils.

ARTEMISIA PYGMAEA GRAY (PIGMY SAGEBRUSH)

Pigmy sagebrush is a dwarf, depressed, evergreen, cushionlike shrub less than 8 inches (2 dm) tall. Bark on older stems becomes dark brown and fibrous. On young branches, the bark is nearly white to straw-colored and somewhat pubernlent. Leaves on the vegetative stems are green, nearly glabrous, 0.08 to 0.16 inch (2 to 4 mm) wide, 0.08 to 0.32 inch (2 to 8 mm) long, and are pinnatified with 3 to 11 lobes, or sometimes may be only toothed. Leaves on the flowering branches are usually reduced and may be entire. Heads with three to five disc flowers are arranged into spikelike inflorescence. Ray flowers are lacking. Twelve to eighteen greenish-yellow bracts subtend each head. Achenes are glabrous. Flowers bloom in August and September, and seed matures in October. Seeds are large for *Artemisia*.

Pigmy sagebrush is limited to calcareous soils in desert areas over approximately 20 mi^2 (5 000 ha) from eastern Utah to western Nevada, and northern Arizona. In Nevada, this species is often associated with the halophytie *Chrysothamnus nauseosus* ssp. *consimilis*. Some fairly large stands occur with black sagebrush in Utah.

ARTEMISIA RIGIDA (NUTT.) GRAY (STIFF OR SCABLAND SAGEBRUSH)

Stiff sagebrush is a low, pungently aromatic shrub with thick, rigid, somewhat brittle branches up to 16 inches (4 dm) high. It is not known to rootsprout or layer. The deciduous, silvery-canescent, spatulate leave are mostly 0.4 to 1.6 inches (1 to 4 cm) long and deeply divided into three to five narrowly linear lobes. Occasionally some leaves are linear and entire. Infloreseence is a leafy spike with heads sessile or in small clusters in the axils of their subtending leaves, which generally are all longer than the heads. The campanulate involuere is 0.16 to 0.20 inch (4 to 5 mm) long with numerous, canescent bracts. Each head consists of 5 to 16 perfect disc flowers. Flowering occurs during Septem-

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shaped and three-toothed or lobed. The upper leaves, however, may be entire and linear to lanceolate or oblanceolate. The foliage is mildly aromatic when crushed.

Flower heads occur singly or occasionally one to three, in short interrupted spike or racemelike inflorescences. Each head contains 6 to 16, rarely as many as 20, disc flowers. Ray flowers are lacking. The 10 to 14 involucral bracts are often brown or purplish. Achenes are granuliferous. Flowers bloom during August and September. Seeds mature during September and October. Plantings of this sage in valley lowlands of central Utah have bloomed profusely, but none of the plants produced mature seed.

Timberline sagebrush covers approximately 100 mi^2 (27 000 ha) between 8,500 and 11,000 ft (2 600 and 3 350 m) elevation in high mountainous areas of central Colorado, western Wyoming, and the central Sierras of California. This species is usually found growing in deep soils along the margins of forests. It is also found in other western States, particularly in the high mountains of Utah and Nevada.

ARTEMISIA TRIDENTATA NUTT. (BIG SAGEBRUSH)

Big sagebrush is a highly polymorphic species with numerous ecotypes and biotypes. Three subspecies (*tridentata, wyomingensis*, and *vaseyana*) are generally recognized and will be discussed individually following the general presentation of the species. The big sagebrush complex is composed of aromatic, evergreen shrubs ranging in size from dwarf to tall, arborescent forms up to 15 ft (4.5 m) tall. The lower forms generally have several main stems arising from the base, whereas the tall forms often have a single short trunk. Older branches are covered with a gray to brown or black shredded bark. Younger branches and leaves have a white to gray tomentum that gives the plants a silvery cast.

Typical leaves are narrowly cuneate or oblanceolate and terminate with three blunt teeth at their truncate apexes. However, considerable variation occurs, ranging from linear, entire leaves with rounded to acute apexes, to broadly cuneate leaves with varying number of teeth or shallow lobes. The leaves also range in size from 0.08 to 0.8 inch (2 mm to 2 cm) broad and 0.4 to 2.6 inches (1 to 6.5 cm) long. Normally, leaves on vegetative shoots are more characteristic and less variable than those on flowering shoots. Also, persistent leaves are less variable than leaves of the spring growth flush, which are shed by midsummer. Heads of this species contain three to eight disc flowers each and are arranged into leafy panicles with erect or sometimes drooping branches. In some forms, the inflorescence becomes spicate. Blooming occurs from July to October. Seeds mature in October, November, and December.

Big sagebrush is the most widespread and common shrub of western North America, especially in the Great Basin. It covers approximately 226,400 mi^2 (58.7 million ha) in the 11 western States, and grows in a variety of soils on arid plains, valleys, and foothills to mountain slopes from 1,600 to 11,200 ft (500 to 3 400 m). Although it is fairly tolerant of some alkaline and acid soils, its optimum growth is in deep, fertile, alluvial loams.

Artemisia tridentata ssp. *tridentata* (basin big sagebrush) is an erect, heavily branched, unevenly topped shrub. This subspecies has trunklike main stems. Shrubs range between 3.3 and 6.6 ft (1 to 2 m) in height. However, some forms may reach 15 ft (4.5 m) in suitable habitats. Mature shrubs are the largest members of the big sagebrush complex. The evergreen, vegetative leaves are narrowly lanceolate, up to 2 inches (5 cm) long by 0.2 inches (5 mm) wide, and typically three-toothed at the apex. The leaves of the flowering stems, however, gradually become smaller and may be linear or oblanceolate and entire. The gray-canescent foliage possesses a strongly pungent, aromatic odor. Flowering stems arise throughout the uneven crown and bear numerous flower heads in erect, leafy panicles. The heads contain three to six small yellowish or brownish, trumpet-shaped, perfect-disc flowers. The narrowly campanulate involucre consists of canescent bracts 0.12 to 0.16 inch (3 to 4 mm) long and about 0.08 inch (2 mm) wide that form four to five overlapping series around each head. The outermost bracts are less than a fourth as long as the innermost bracts. Flowering occurs from late August to October. Seed matures, depending on site, from October to November.

Basin big sagebrush was at one time the most abundant shrub in western North America on lowland ranges. It normally occurs on dry, deep, well-drained soils on plains, valleys, and foothills below 7,000 ft (2 000 m) elevation. Vigorously growing basin big sagebrush is considered indicative of productive ranges because it often grows in deep, fertile soil. This subspecies has generally been regarded as intolerant of alkali, but there are ecotypes that grow in relatively high alkalinity in association with such alkali-tolerant plants as black greasewood, shadscale saltbush, and saltgrass (*Distichlis stricta*). Plants with strikingly reflexed drooping branches of inflorescence are found throughout the range of ssp. *tridentata*. These have been termed *A. tridentata* ssp. *tridentata* f. *parishii*.

Artemisia tridentata ssp. *vaseyana* (mountain big sagebrush) is normally a smaller shrub than basin big sagebrush. Its main stem is usually divided at or near the ground, and it tends to have a spreading, evenly topped crown. The vegetative branches are usually less than 3.3 ft (1 m) high and sometimes layer at the base. There are, however, ecotypes at lower elevations that may reach about 6.6 ft (2 m) in height. The persistent vegetative leaves are broadly cuneate to spatulate and are characteristically wider than those of basin big sagebrush. When looking down at this shrub, the terminal leaves on each twig appear to be distinctly whorled. Subspecies *tridentata* does not show this trait, but ssp. *wyomingensis* shows the trait to some extent. Normally, the leaves are 0.8 inch (2 cm) long, 0.2 inch (5 mm) broad, but in form *spiciformis* may reach 2.6 inches (6.5 cm) long and 0.8 inch (2 cm) broad. Crushed leaves emit a rather pleasant mintlike fragrance in contrast to the more pungent odor of both basin and Wyoming big sagebrush. Flower heads are arranged into narrow, often dense panicles. The heads contain five or six trumpet-shaped, perfect-disc flowers. The broadly campanulate involucre consists of numerous canescent overlapping bracts, 0.2 inch (5 mm) long and 0.12 to 0.16 inch (3 to 4 mm) wide. The outermost bracts are less than half as long as the innermost. Some strains of mountain big sagebrush start blooming as early as July and thus may be in bloom up to 6 weeks earlier than either basin or Wyoming big sagebrush. Seed matures from September through October.

In the Intermountain West, mountain big sagebrush occurs in the upper elevational range of the big sagebrush zone in deep, well-drained soils on mountain slopes from below 4,600 ft (1 400 m) for f. *xericensis* and at elevations over 9,800 ft (3 000 m) for f. *spiciformis*. The form *xericensis* is unevenly topped and grows in relatively dry sites similar to basin and Wyoming big sagebrush. Chromatographically, cytologically, and phenologically, *xericensis* most closely resembles ssp. *vaseyana*. The form epithet "*xericensis*" has not been validly published. Hanks and others (1973) used an analogous term: low elevation

vaseyana. Form *spiciformis* has larger flower heads and leaves than typical *vaseyana* and is found at higher elevations in the cooler, more mesic sites. Subspecies *vaseyana* grows in slightly acid to slightly alkaline soils. Unlike ssp. *tridentata*, *vaseyana* is rarely associated with any of the saltbushes.

Artemisia tridentata ssp. *wyomingensis* (Wyoming big sagebrush) is the most xeric subspecies of *A. tridentata*. Occasionally, all three subspecies may be found growing together. Whenever it is found associated with ssp. *tridentata*, ssp. *wyomingensis* is growing in the poorer, more shallow soils. Subspecies *wyomingensis* is a low shrub usually less than 39 inches (1 m) in height. It has an uneven top with flower stalks arising throughout the crown like ssp. *tridentata*. Its main stems branch at or near the ground level like ssp. *vaseyana*, but it does not layer. Leaves are 0.4 to 0.8 inch (1 to 2 cm) long, narrowly cuneate to cuneate. Flower heads contain three to six disc flowers and are arranged into panicles narrower than the paniculate inflorescence of *tridentata* and wider than the spicate inflorescence of *vaseyana*. Flowering and seed ripening take place later than *vaseyana* and earlier than *tridentata*. Wyoming big sagebrush is abundant throughout the Intermountain region and east of the Continental Divide in Montana, Wyoming, and parts of Colorado in dry, shallow, gravelly soil, usually from 5,000 to 7,000 ft (1 500 to 2 100 m). In Idaho, this subspecies is found from 2,500 to 6,500 ft (760 to 1 980 m) in the hotter, drier portions of the State.

ARTEMISIA TRIPARTITA RYDB. (THREETIP SAGEBRUSH)

Threetip sagebrush is a rounded, evergreen shrub up to 3.3 ft (1 m) high. It may have a simple, trunkline main stem or many branches arising from the base. The bark on young branches is canescent, but becomes shredded and grayish, light brown to dark brown or black on older stems. This species can layer, sometimes sprouts back after a burn, and may sprout from the stump following herbicide treatments. Leaves of the vegetative branches are canescent, 0.2 to 1.6 inches (0.5 to 4 em) long, and typically deeply divided into three linear or narrowly linear-lanceolate lobes, which in turn may be three-cleft. Some of the upper leaves are often entire. Crushed foliage emits a pungent odor. Flower heads contain 3 to 11 disc flowers and are normally arranged into panicles. Ray flowers are lacking. Each head is subtended by 8 to 12 caneseent involucral bracts. Achenes are resinous-granuliferous. Blooming occurs from July to September.

Threetip sagebrush covers approximately 13,000 mi^2 (3.4 million ha) in the Northern Rocky Mountains and Great Basin States from British Columbia south through Montana and Wyoming to Colorado and west to Washington, Oregon, northern Nevada, and northern Utah at elevations between 3,000 and 9,000 ft (900 and 2 750 m). In some places, particularly in Idaho, this species occurs between the lower, hot, dry sites dominated by Wyoming big sagebrush and the higher, cooler sites dominated by mountain big sagebrush.

Artemisia tripartita ssp. *rupicola* (Wyoming threetip sagebrush) is a dwarf shrub with decumbent branches that rarely grow over 6 inches (1.5 dm) tall. It is frequently found layering and may have a crown spread of 12 to 20 inches (3 to 5 dm). Leaves of the vegetative branches are often 1.2 inches (3 cm) long and deeply divided into linear lobes, each at least 0.04 inch (1 mm) wide. Flower heads bear 3 to 11 disc flowers and are arranged into leafy, narrowly racemose panicles. Flowers bloom in late August and September. Seed ripens in October. Wyoming threetip sagebrush has a rather limited range. It occurs on rocky knolls from 7,000 to 9,000 ft (2 430 to 2 740 m) in elevation in central and southeast Wyoming. Brunner (1972) reported this snbspecies also occurs in southern Oregon but has not yet been found in Nevada. It typically grows on sites adjacent to those of mountain big sagebrush.

Artemisia tripartita ssp. *tripartita* (tall threetip sagebrush) is a freely branching shrub up to 3.3 ft (1 m) high. It can layer easily when the conditions are right, but is seldom found layering in the field. After burning, it sometimes sprouts. Leaves of the vegetative branches are 0.6 to 1.6 inches (1.5 to 4 cm) long and deeply divided into three linear lobes less than 0.04 inch (1 mm) wide. Flower heads bear four to eight disc flowers and are arranged in panicles that may sometimes be reduced to a spicate form. Flowers bloom in late August and September. Seeds ripen in October. This subspecies occurs in dry, well-drained soils at 3,000 to 7,500 ft (900 to 2 300 m) elevation from British Columbia south through Washington to northern Nevada and eastward to northern Utah and western Montana.

Sagebrush-Soil Relations

Hironaka (1979) pointed out that edaphic considerations are very important in the distribution of sagebrush taxa. Although there are many exceptions, general distribution of sagebrush is related to soil moisture, temperature, depth, and parent material. Some of his specific observations regarding soil relations in the Pacific Northwest are summarized in the following paragraphs.

In general, *Artemisia tridentata* ssp. *tridentata* tends to occupy the deep soils with minimal development in the low to moderate precipitation zone, whereas ssp. *wyomingensis* occupies soils of moderate depth. As moisture conditions and temperature improve with increase in elevation, ssp. *vaseyana* dominates until it gives way to f. *spiciformis* on deep soils at high elevations.

The position of *Artemisia tripartita* ssp. *tripartita* along the moisture gradient overlaps the upper portion of *A. tridentata* ssp. *wyomingensis* and the lower portion of ssp. *vaseyana*. Apparently, it is not associated with a particular kind of soil.

On shallow soils, dwarf sagebrush species replace the tall species. *Artemisia nova* occupies the lower position along the moisture gradient and is restricted to limestone-derived soils in the drier areas. Where *A. arbuscula* is associated with *A. nova*, the former consistently occurs in the cooler and higher moisture situations. *Artemisia arbuscula* also occurs on shallow, noncalcareous soils with strongly developed claypans in southwestern Idaho and eastern Oregon. These soils are supersaturated during the spring, but during the summer the plants are under considerable moisture stress.

Artemisia longiloba occurs in habitats similar to those that support *A. arbuscula* on shallow soils with claypans. Sometimes both species are found in the same stand. *Artemisia rigida* also occurs on similar habitats, but on the more shallow and rocky portions.

CLASSIFICATION OF SAGEBRUSH ECOSYSTEMS

The need to classify vegetation and land units has long been recognized by natural resource managers, resulting in the development and use of numerous classification systems. Unfortunately, such classifications have stressed current site occupancy

and identity by a few commercially important plants. Little consideration has been given to the successional status of existing vegetation or to potential productivity of the environment as reflected by the climax vegetation (Mueggler and Stewart 1980).

The range site classification developed by Dyksterhuis (1949) was adopted by the Soil Conservation Service, and in recent years by the Bureau of Land Management. Although the basis of this classification is climax vegetation, emphasis is placed on site productivity, and nomenclature is descriptive of site and vegetation (Tisdale and Hironaka 1981).

During the past decade, the habitat type concept of classification developed by Daubenmire (1952) has gained increasing acceptance, particularly by the Forest Service. This system stresses the use of the entire climax plant community as an environmental integrator, permitting identification of habitats with similar biotic potentials. Consequently, a particular habitat type has the potential for supporting the same climax vegetation regardless of the plant communities that presently occupy the area. Although vegetation is primarily used to identify and characterize the habitat type, knowledge of soil relations is important, especially where the original vegetation has been altered by grazing, fire, or other manipulations (Tisdale and others 1969). However, different soils may be capable of supporting the same climax vegetation, but with varying levels of productivity.

The habitat type is generally named after the unique combination of dominants in the overstory and understory. Factors other than climax vegetation may be used to delineate areas of similar potential, but they are not usually as satisfactory for assessment of comparable environments. Climax vegetation reflects the environment and provides a means of recognizing similar areas. Although soils and other factors are also useful in classification, vegetation is most easily observed and is the basic resource being directly managed. A binomial nomenclature system is usually adequate, but sometimes a trinomial is necessary (Hironaka and Fosberg 1979).

Sagebrush-grass communities have received considerable study, particularly in the Pacific Northwest (Passey and Hugie 1962; Franklin and Dyrness 1969; Schlatterer 1972; Hall 1973; Lewis 1975). But classification based strictly on the habitat type concept has been largely limited to work by Daubenmire (1970), Winward (1970), Zamora and Tueller (1973), Bramble-Brodahl (1978), Hironaka (1979), Hironaka and Fosberg (1979), Mueggler and Stewart (1980), and Tueller (unpublished manuscript). Figure 2 is an expansion of the compilation by Hironaka (1979) for Idaho, Oregon, and Washington to include Montana, Nevada, and Wyoming.

Identical or similar habitat types, especially if they occur in widely separated areas, may be only superficially alike. This stems from the practice of naming habitat types after the unique combinations of dominant and codominant species without sufficient regard for lesser species that may have considerable influence on characteristics and dynamics of the community. Accordingly, specific descriptions of the various habitat types (such as Daubenmire 1970; Zamora and Tueller 1973; Hironaka and Fosberg 1979; Mueggler and Stewart 1980) should be consulted before similarity is assumed and successful management prescriptions are widely extrapolated. If significant differences exist, management must be adjusted to accommodate them.

Obviously, the list of sagebrush-grass habitat types is far from complete. Utah and Colorado have been largely ignored, as well as several other western States. It is estimated that not more than half of the existing habitat types are included above. Because of the numbers involved, and dearth of specific information, individual management prescriptions cannot be developed for or applied to each habitat type at the present time. Rather, an attempt will be made in this publication to develop general guides for sagebrush-grass ranges with necessary modification tailored to peculiarities of certain habitat types.

Dwarf sagebrush group

1. *A. arbuscula* ssp. *arbuscula/Agropyron spicatum* (I,O,W,M,N)
2. *A. arbuscula* ssp. *arbuscula/Festuca idahoensis* (I,O,W,M,N)
3. *A. arbuscula* ssp. *arbuscula/Poa sandbergii* (I)
4. *A. arbuscula* ssp. *arbuscula/Stipa thurberiana* (N)
5. *A. arbuscula* ssp. *arbuscula/Purshia tridentata/Agropyron spicatum* (N)
6. *A. arbuscula* ssp. *thermopola/Festuca idahoensis* (I)
7. *A. longiloba/Agropyron spicatum* (Wy)
8. *A. longiloba/Festuca idahoensis* (I,O,N,Wy)
9. *A. nova/Agropyron spicatum* (I,N)
10. *A. nova/Festuca idahoensis* (I)
11. *A. nova/Agropyron inerme* (N)
12. *A. nova/Stipa comata* (N)
13. *A. nova/Oryzopsis hymenoides* (N)
14. *A. rigida/Poa sandbergii* (I,O,W)

Tall sagebrush group

1. *A. cana* ssp. *viscidula/Agropyron caninum* (Wy)
2. *A. cana* ssp. *viscidula/Festuca idahoensis* (I,Wy)
3. *A. rothrockii-A. tridentata* ssp. *vaseyana* f. *spiciformis*/mt. forb (Wy)
4. *A. tridentata* ssp. *tridentata/Symphoricarpos oreophilus-Agropyron spicatum* (Wy)
5. *A. tridentata* ssp. *tridentata/Agropyron spicatum* (I,O,W,M)
6. *A. tridentata* ssp. *tridentata/Elymus cinereus* (I,O,W)
7. *A. tridentata* ssp. *tridentata/Festuca idahoensis* (I,O,W)
8. *A. tridentata* ssp. *tridentata/Poa sandbergii* (O,W)
9. *A. tridentata* ssp. *tridentata/Stipa comata* (I,W,N)
10. *A. tridentata* ssp. *vaseyana/Agropyron spicatum* (I,O,M,Wy)
11. *A. tridentata* ssp. *vaseyana/Festuca idahoensis* (I,O,M,Wy)
12. *A. tridentata* ssp. *vaseyana/Festuca scabrella* (M)
13. *A. tridentata* ssp. *vaseyana/Stipa comata* (I,Wy)
14. *A. tridentata* ssp. *vaseyana/Symphoricarpos oreophilus/A. spicatum* (I,Wy,N)
15. *A. tridentata* ssp. *vaseyana/Symphoricarpos oreophilus/F. idahoensis* (I,Wy,N)
16. *A. tridentata* ssp. *vaseyana/S. oreophilus/Carex geyeri* (I)
17. *A. tridentata* ssp. *vaseyana* f. *spiciformis/Bromus carinatus* (I)
18. *A. tridentata* ssp. *vaseyana* f. *spiciformis/Carex geyeri* (I)
19. *A. tridentata* ssp. *vaseyana* f. *spiciformis/Festuca idahoensis* (I)
20. *A. tridentata* ssp. *vaseyana* f. *xericensis/Agropyron spicatum* (I)
21. *A. tridentata* ssp. *vaseyana* f. *xericensis/Festuca idahoensis* (I)
22. *A. tridentata* ssp. *wyomingensis/Agropyron spicatum* (I,O,M)
23. *A. tridentata* ssp. *wyomingensis/Poa sandbergii* (I)
24. *A. tridentata* ssp. *wyomingensis/Sitanion hystrix* (I)
25. *A. tridentata* ssp. *wyomingensis/Stipa thurberiana* (I)
26. *A. tridentata* ssp. *wyomingensis/Stipa comata* (I)
27. *A. tripartita* ssp. *tripartita/Agropyron spicatum* (I)
28. *A. tripartita* ssp. *tripartita/Festuca idahoensis* (I,W,M)
29. *A. tripartita* ssp. *tripartita/Stipa comata* (I,W)

Figure 2.—List of sagebrush-grass habitat types reported for Idaho (I), Oregon (O), Washington (W), Montana (M), Nevada (N), Wyoming (Wy).

CONDITION AND TREND

General Considerations

Range condition or health is the status of vegetal cover and soil in relation to a standard or ideal for a particular habitat type or site (Ellison and others 1951). Trend is change in condition. Condition and trend are recognizable by certain indicators that can be seen in soil and vegetation. These indicators help to interpret past and current changes in the ecosystem, and often suggest what may be expected in the future.

Reliable judgment of condition and trend is essential to effective evaluation of the success or failure of range management practices. Consequently, the range manager must be able to identify the plants and habitat types or sites, to understand ecological principles including patterns of and reasons for change, and to properly interpret change as a basis for needed adjustment in management prescriptions.

Soil stability is an essential requirement of satisfactory condition. In other words, vegetal cover must be sufficient to protect the soil from accelerated erosion. Besides quantity of vegetation, quality is important and is usually satisfied by a mixture of perennial grasses and forbs.

Judgment of range condition usually must be made in relation to pristine. For the most part, the best approximation is a relic area that has never been grazed by livestock or otherwise disturbed. However, this does not mean that pristine condition is the management objective. It serves only as a guide to indicate what quality and quantity of vegetation the area is capable of supporting, character of the litter cover, and normal appearance of the surface soil. Comparisons can be made only between ranges of similar potential; therefore, judgment of condition should be preceded by classification of range ecosystems into habitat types or range sites.

Fluctuations in weather must be accepted as normal events whose effects must be considered when judging range condition. Variations in amount of precipitation and patterns of distribution greatly affect plant development and yield (Blaisdell 1958), but their influence on soil stability is usually minor.

Trend may result from some degree of change in any component of the ecosystem. For practical purposes, however, only soil and vegetation need be considered in assessment of trend, which is simply the recognition of the nature, rapidity, and direction of ecological change. In determining trend, one must distinguish between those cumulative changes that produce a real difference in condition and those that are mere fluctuations. For example, a large crop of seedlings of desirable perennial species may reflect only a temporarily favorable combination of circumstances. A surer indication of upward trend would be plants of successively older age classes in addition to the seedlings (Ellison and others 1951). These authors have made a comprehensive evaluation of 21 important indicators of range condition and trend including cover, bare soil surface, observed movement of soil, trampling displacement, soil remnants, erosion pavement, lichen lines, active gullies, wind-scoured depressions, aeolian deposits, alluvial deposits, vegetal composition, age classes, annual weeds, invasion of bared surfaces, vegetation in gullies, rill-channel ridges, accessibility of palatable species, relics, hedged shrubs, and current utilization. These indicators provide clues to events that have happened, are happening, or will happen on the range-watershed. Although they have particular application to the subalpine zone, most are worthy of serious consideration as indicators of condition and trend on any rangeland grazed by livestock.

Sagebrush-Grass Ecosystems

Information on sagebrush-grass ecosystems is meager; however, general guides for recognizing condition and trend were developed in southern Idaho by Pechanec and Stewart (1949). These can be broadly used by a manager to make reasonable judgments of range condition and trend for a variety of habitat types or sites, especially those at intermediate and low elevations.

CONDITION

Condition may be judged by such characteristics as relative vigor and abundance of good and poor forage plants, and extent of soil erosion. Four condition situations can be readily recognized:

1. Sagebrush with a good understory of perennial grasses and forbs (fig. 3). Such ranges have not been greatly changed from their original condition, and forage production is not far below the potential. The understory is composed of palatable perennial grasses and forbs, which make up more than a third of the total vegetation and are abundant in the spaces between sagebrush plants. However, they usually do not form a solid cover and some bare ground can be expected. Sagebrush is in open stands. Soils are essentially unchanged from their original condition, with no observable erosion. Condition is classed as good or excellent.

Figure 3.—Closeup of an *Artemisia tripartita* ssp. *tripartita*/*Agropyron spicatum* habitat type in excellent condition near headquarters of the U.S. Sheep Experiment Station, Dubois, Idaho. The prominent forb is *Balsamorhiza sagittata*.

2. Sagebrush with a sparse understory of perennial grasses (fig. 4). On these ranges perennial grasses have been reduced to a scattered stand, sagebrush has greatly thickened, and perennial forbs are virtually lacking. Erosion is often severe, but on level sites soil may be in relatively good condition because of protection by the dense sagebrush cover. Forage production is light and mostly unavailable to grazing animals. Range condition is poor to fair.

3. Sagebrush with an understory of annual grasses and weeds. These ranges are characterized by a dense stand of sagebrush with an understory of annuals. Perennial grasses are present only

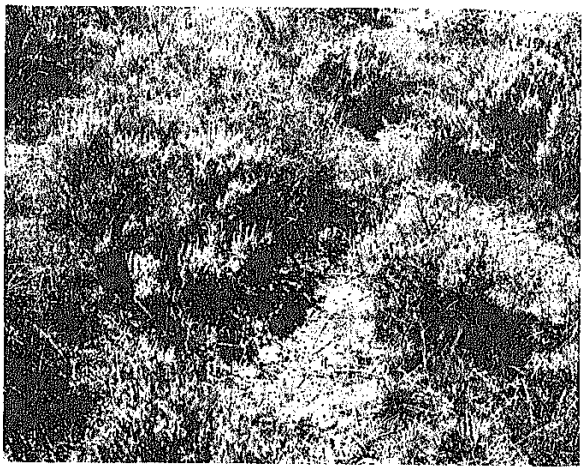


Figure 4.—Same habitat type as figure 3, this time in fair condition. Note the absence of forbs.

as scattered individuals. Severe erosion has often occurred as indicated by erosion pavement or pedestaled plants. On level ground, however, the soil surface may be rather well preserved even though the forage cover is depleted. The already poor forage production is unstable in quantity from year to year. Range condition is classed as very poor to poor.

4. Ranges with sagebrush replaced by cheatgrass or other annuals. Ranges on which sagebrush and other original species have been destroyed by recurrent fires, cultivation, or grazing, now support nearly pure stands of annual grasses or weeds. Soil losses are often severe; however, soil condition of some cheatgrass ranges may be good. Although forage production on such ranges can be high, it is highly variable and may be extremely low in years of scanty precipitation.

TREND

Knowledge of trend is essential in planning and evaluating a grazing program. For each of the four categories described above, trend in condition is shown by distinct plant or soil indicators. With the exception of accelerated erosion, a single indicator is seldom sufficient to depict trend. Although a careful inspection may reveal apparent trend, observation of indicators over a series of years may be necessary for definite confirmation.

1. Sagebrush with a good understory of perennial grasses and forbs. **Improvement or maintenance** of ranges already in satisfactory condition will be accompanied by few or no indicators of trend. Palatable grasses and forbs should be vigorous, and a few seedlings may be in the process of becoming established. Few sagebrush seedlings are evident, and soil is stable.

Indicators of **downward trend** on good-condition threetip sagebrush (*Artemisia tripartita*) range at the U.S. Sheep Experiment Station in southeastern Idaho were precisely documented by Peehanec (1945). The first signs became evident within 3 years after the pastures were overstocked. The indicators in order of occurrence were: decrease in vigor of palatable perennial forbs and the fine grasses, increase in number and size of annuals, decrease in vigor of the robust perennial bunchgrasses, establishment of numerous young sagebrush plants in the openings, death of parts of perennial forb and grass clumps, and excessive pedestaling of bunchgrasses. Many of these changes are illustrated by the photographs in figure 5.

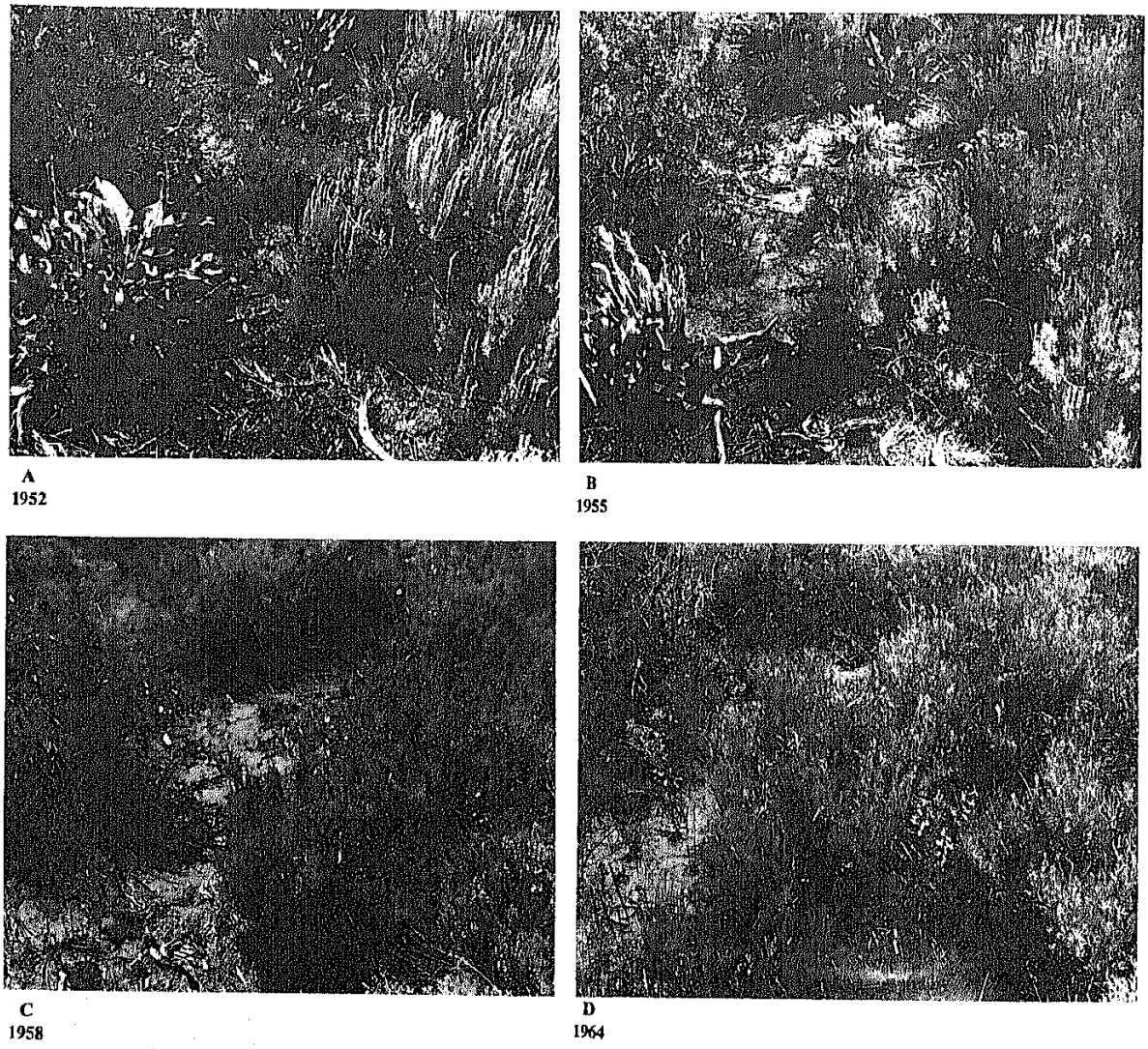
2. Sagebrush with a sparse understory of perennial grasses. **Upward trend** is indicated by increase in vigor of perennial grasses and forbs and establishment of a few seedlings. Although a few sagebrush seedlings may be present, production of sagebrush usually declines as a result of loss in vigor of established plants. There should be a slight accumulation of litter and less prominent pedestaling of bunchgrasses. Such changes are illustrated in figure 6. **Downward trend** is indicated by increase in sagebrush and annuals such as cheatgrass. Such changes are accompanied by a decrease in palatable perennial grasses and forbs and establishment of young sagebrush plants in the openings.

3. Sagebrush with an understory of annuals or range with sagebrush replaced by annuals. Natural **improvement** of vegetation on such areas will usually be extremely slow; consequently, upward trend must be judged primarily by increase in litter and stabilization of the soil. Establishment of a few seedlings of perennial grasses and forbs may occur. **Downward trend** may be indicated by low vigor of annuals, replacement of cheatgrass by weeds, and by active gully and wind erosion.

Although the above indicators of condition and trend generally apply to sagebrush-grass vegetation, they have only limited value in habitat types dominated by such palatable species as black sagebrush (*Artemisia nova*). As described by Hutchings and Stewart (1953), **upward trend** is indicated by an increase in black sagebrush and palatable perennial grasses such as Indian ricegrass (*Oryzopsis hymenoides*), whereas a decrease in these species, along with an increase in such unpalatable species as small rabbitbrush (*Chrysothamnus viscidiflorus* ssp. *stenophyllus*), denotes a **downward trend.**

Special situations must be recognized and evaluated by different standards. For example, a depleted area of sagebrush-grass range that has been satisfactorily revegetated with desirable exotic species can be considered to be in good condition provided soil is stable and yield of vegetation is near potential for the site and in line with management objectives. These may be considerably different from those of native sagebrush-grass range. In this paper, however, condition and trend for the most part are considered in relation to natural vegetation and deviations therefrom. Deliberate manipulations for specific management goals are recognized but not addressed in detail.

Condition and trend of sagebrush-grass ranges cannot be adequately evaluated without an examination of included riparian and aquatic areas, which may be particularly sensitive indicators of what is happening on the range as a whole. Not only do livestock tend to concentrate in such areas and have serious direct impacts on vegetation, soil, and water quality, but these areas can also be severely damaged by runoff and erosion from surrounding poor condition range. It is axiomatic, then, that a sagebrush-grass range unit is not in good condition unless the riparian and aquatic portions are also in satisfactory condition.



A
1952

B
1955

C
1958

D
1964

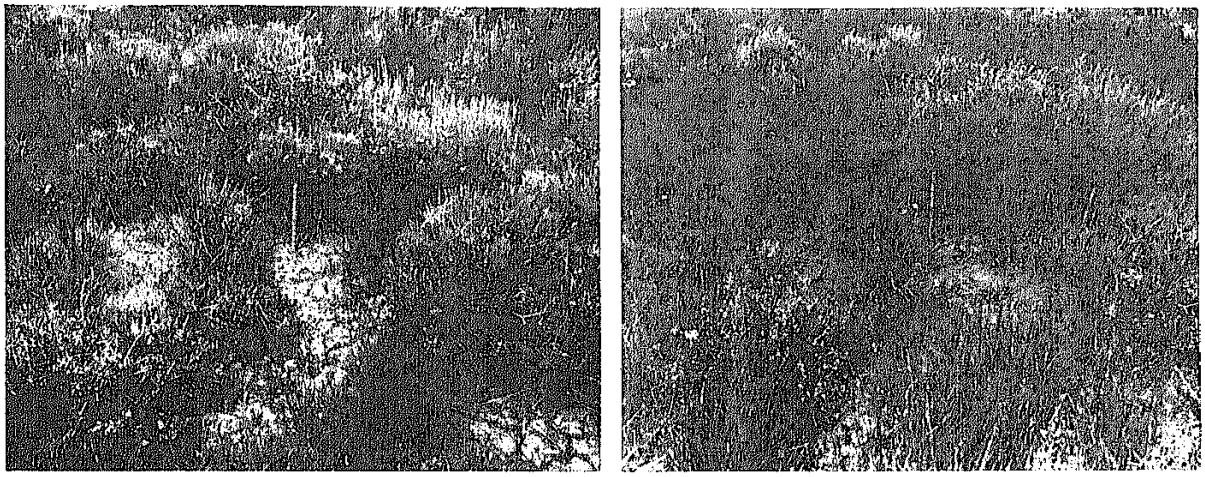
Figure 5.—Plot in *Artemisia tripartita/Agropyron spicatum* habitat type showing deterioration from excellent to poor condition as a result of high-intensity spring use by sheep. Grass in photo D is largely cheatgrass (from Laycock 1967).

MANAGEMENT

Management objectives for sagebrush-grass ranges may be described in a number of ways: wise multiple use, maintenance or improvement of vegetation and soil, or perhaps optimum sustained-yield of livestock and wildlife consistent with other uses and values. Although emphasis may vary with specific conditions or situations, it seems logical to direct primary attention to conservation of the basic resource, soil and vegetation. Having these factors in natural or pristine condition is perhaps a theoretical goal, for it must be recognized that such condition can seldom be achieved under practical use, especially livestock grazing that is foreign to the original ecosystem. Furthermore, a considerable portion of the sagebrush-grass area has been so modified by past use that restoration to the natural condition will not be possible during the foreseeable future, even under intensive management. Nevertheless, the pristine concept should be retained as a guide to indicate possible vegetation and soil conditions for particular habitat types or range sites.

Although stable soil is always a prerequisite to satisfactory condition, vegetation is more easily observed and measured. Consequently, effectiveness of management is usually judged by vegetal response. Despite great diversity in the various habitat types of sagebrush-grass range, the prevalent now situation is too much sagebrush and other low-value shrubs, too many annuals, and not enough perennial grasses and forbs. Simply stated, then, vegetation management often requires a reduction is sagebrush and an increase in perennial grasses and forbs.

If deterioration has not progressed too far, it may be possible to use grazing management itself to bring about needed improvement in vegetation. However, sagebrush is an aggressive, long-lived shrub, and direct control measures followed by revegetation with herbaceous species may be necessary to restore the range to a satisfactory condition.



A
1952

B
1964

Figure 6.—Increase in ground cover and production of perennial grasses and forbs as a result of shifting from spring to fall grazing by sheep (from Laycock 1967).

Sagebrush Control

Control of undesirable plants is often essential to substantial improvement of sagebrush-grass range. Normally, sagebrush is the target species, but control of other low-value shrubs, annuals, or noxious weeds may be necessary. Burning, spraying, and mechanical methods have all been used effectively. Biological measures such as manipulation of insects, diseases, and mammals are also possibilities.

No method is universally the best because sagebrush taxa are highly variable, and they grow under widely different conditions. Suitability of a particular method depends upon such factors as density, height, and age of the sagebrush stand, associated shrubs, amount and kind of grasses and forbs in the understory, topography and rockiness of the area, type of soil and susceptibility to erosion, available equipment, size of the area to be treated, planned use, and personal preference. In choosing a method, the following points are important (Pechanec and others 1965): (1) use a method that will accomplish a satisfactory kill of sagebrush and associated undesirable species; (2) if seeding is not necessary, use a method that causes minimum damage to desirable species of grasses, forbs, and shrubs; (3) if seeding is planned, use a method that kills most of the vegetation and leaves a suitable seedbed; (4) use a method that will not increase erosion hazards; and (5) choose a method that is most economically consistent with the above guidelines.

BURNING

Fire is a natural component of many sagebrush-grass ecosystems, and any site producing vegetation dense enough to carry a fire has undoubtedly burned many times in its developmental history. Since plant species vary greatly in their response, fire—either natural or deliberately set—can be used to control some species while favoring others. Despite the general tolerance of vegetation and soil to fire, undesirable impacts do occur. These can be minimized if the manager has an understanding of fire ecology that he can use to select the area to be burned and choose the best season for doing so.

Habitat types dominated by such big sagebrushes as *A. tridentata* ssp. *tridentata, vaseyana*, and *wyomingensis; A. tripartita*; and *A. cana* often provide enough fuel to carry a fire. However, if the understory has been depleted by past abuse or removed by current utilization, there may not be enough fuel for successful burning. Habitat types of the dwarf species (*A. nova, arbuscula, rigida, pygmaea*, and *longiloba*) seldom support enough vegetation to carry a fire, so other methods of plant control will usually be necessary. At any rate, each situation must be carefully examined and evaluated before burning can be prescribed as a plant control measure.

Ecological Effects

Response of mountain big sagebrush (*A. tridentata* ssp. *vaseyana*) and associated species was studied on a prescribed burn at the U.S. Sheep Experiment Station in southeastern Idaho for 30 years, 1936-66 (Blaisdell 1953; Harniss and Murray 1973). Burning was accomplished according to plan in August 1936. An initial inventory of vegetation was made prior to burning in 1936 with followup observations on permanent plots in 1937, 1939, 1948, and 1966. Prior to burning, the area supported a dense stand of sagebrush, beneath which was an open but fairly continuous stand of perennial grasses. Roughly, the vegetation was 35 percent perennial grasses, 5 percent perennial forbs, 5 percent annual forbs, 40 percent sagebrush, and 15 percent rabbitbrush, horsebrush, and other shrubs. Although absolute values in pounds per acre were determined for the various species, trends were expressed as percentages of production on unburned range.

With a few exceptions, relative production of all grasses decreased the year after burning, and these decreases varied roughly in proportion to burn intensity. Thickspike wheatgrass (*Agropyron dasystachyum*) and plains reedgrass (*Calamagrostis montanensis*) were only slightly affected, but decreases were severe in Idaho fescue (*Festuca idahoensis*) and needle-and-

thread (*Stipa comata*), especially on high-intensity burns. Within 3 years thickspike wheatgrass and plains reedgrass made substantial gains on burns of all three intensities, and yields continued to increase during the next 9 years. Idaho fescue, prairie junegrass (*Koeleria cristata*), and needle-and-thread made partial recovery during the first 3 years, and bluegrasses (*Poa sandbergii* and *P. nevadensis*) completely recovered on all but the heavy burn. After 12 years, only Idaho fescue on the heavy burn had not regained its loss. During the following 18 years, however, thickspike wheatgrass, plains reedgrass, bluebunch wheatgrass, and needle-and-thread all decreased, and bluegrasses and Idaho fescue continued to increase. Therefore, 30 years after burning, relative yields of the various grasses were near their preburn levels (fig. 7).

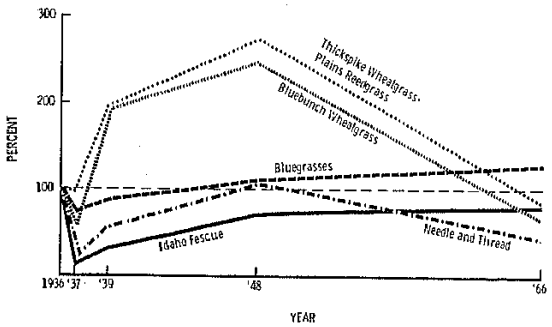


Figure 7.—Trends of important grass species on a planned burn near Dubois, Idaho, 1936-66. Values are adjusted for the natural variation (a) between burned and unburned plots and (b) between years (from Harniss and Murray 1973).

Total forbs decreased the year after burning, but they regained their original yield within 3 years. Rhizomatous forbs generally increased the first year, but suffrutescent species (perennial forbs with partially woody stem bases that do not die down to the ground each year), especially buckwheat (*Eriogonum heracleoides*) and pussytoes (*Antennaria* spp.), decreased markedly on burns of all intensity. Rhizomatous species continued to increase through the third year and then decreased. After initial decreases, suffrutescent species increased during the next 9 years and regained much of their original losses.

Sagebrush was practically eliminated, and its reestablishment from seed was slow, whereas rabbitbrush (*Chrysothamnus viscidiflorus* ssp. *puberulus*) and horsebrush (*Tetradymia canescens* var. *inermis*) sprouted profusely. These sprouts quickly regained or surpassed the original size of the shrubs and produced seed for establishment of new plants. Consequently, yield of rabbitbrush and horsebrush was increased by the third year after burning despite the initial decrease. These species continued their rapid increase during the following 9 years, but sagebrush made only slight recovery. Sometime during the next 18 years, however, substantial decreases occurred in rabbitbrush and horsebrush accompanied by a great increase in sagebrush (fig. 8).

Vegetation trends during the 30 years demonstrate the overwhelmingly dominant role of mountain big sagebrush in the community under study. After increasing during the first 12 years following burning, nearly all species of grasses, forbs, and shrubs decreased in yield during the subsequent 18 years as sagebrush regained control of the area.

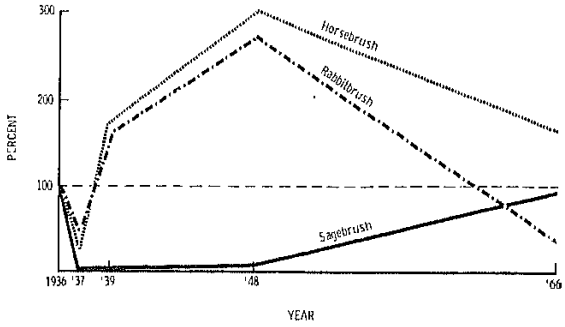


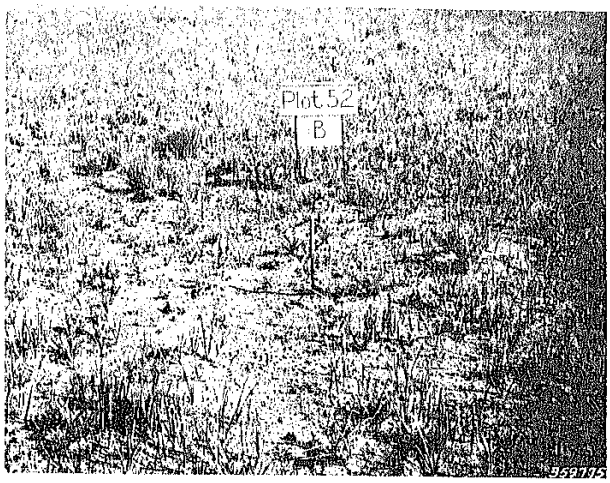
Figure 8.—Trend of important shrub species on a planned burn area near Dubois, Idaho, 1936-66. Values are adjusted for the natural variation (a) between burned and unburned plots and (b) between years (from Harniss and Murray 1973).

The ability of mountain sagebrush to reinvade the vigorous stand of grass that became dominant following the burn was somewhat surprising, as Blaisdell (1949) had previously concluded from revegetation studies that good stands of grass established prior to sagebrush suppress the sagebrush seedlings or entirely prevent sagebrush establishment for an indefinite period. However, Frischknecht (1968) indicated that in years of high precipitation sagebrush can invade both grazed and ungrazed stands of crested wheatgrass (*Agropyron cristatum* and *A. desertorum*). Apparently, competition for soil moisture is less severe during such years.

In the following discussion, an attempt is made to provide a more complete description of what happens to sagebrush-grass vegetation after burning. During the early part of the first growing season, it is evident that actual damage to vegetation far outweighs the benefits. Perennial grasses and forbs are clearly lowered in vigor, as old plants are badly broken up and remaining plants are small and scattered. Although rhizomatous species are apparently less damaged than others, even these have poor vigor. Shrubs are represented by only a few sprouts. Much bare ground is exposed, but an abundant growth of annuals may fill many of the openings. As the season progresses, new shoots of rhizomatous grasses and forbs appear, and tuft-forming species begin to stool out; however, scarcely any flower stalks are produced. Grasses and forbs remain green about 2 weeks longer than on unburned areas. The appearance of a typical year-old burn is shown in figure 9A.

During the second year, perennial grasses and forbs continue to increase and vigor is high. Sprouting shrubs are larger, but are still an inconspicuous part of the vegetation. The most noticeable feature of burns during the second growing season is abundant flower stalk production of almost all grasses and forbs (fig. 9B). Why this occurs is not known, but it may be related to a temporary increase in mineral nutrients and increased soil moisture. At any rate, seed is provided for revegetation of areas that may not be supporting a full plant cover.

Total herbage production of grasses and forbs reaches a maximum within a few years after burning, largely as a result of increases in the fire-resistant rhizomatous species. Although this increased production may persist indefinitely, more often it declines in subsequent years. This general decline in grasses and forbs is accompanied by an increase in shrubs and many nonrhizomatous herbaceous perennials.



A
1937

B
1938

Figure 9.—(A) Plot in the *Artemisia tridentata* ssp. *vaseyana*/*Agropyron spicatum* habitat type at the U.S. Sheep Experiment Station 1 year after burning. Grasses are mostly rhizomatous species—*Agropyron dasystachyum* and *Calamagrostis montanensis*. (B) Same plot 2 years after burning. Note the abundant flower stalk production of the grasses.

Shrubs are apparently more damaged by burning than either grasses or forbs. Not only is the current herbage destroyed by fire, but the aboveground woody parts are either killed or completely consumed, resulting in destruction of stored reserves. This may also be the reason that suffrutescent forbs are more severely damaged than other forbs having no aboveground, perennial parts. However, such species as rabbitbrush, horsebrush, snowberry (*Symphoricarpos oreophilus*), and chokecherry (*Prunus virginiana*) sprout profusely and are only temporarily injured (fig. 10A). Sprouting of bitterbrush (*Purshia tridentata*) is highly variable, ranging from 0 to 60 percent. Apparently, amount of sprouting is related to inherent characteristics and to intensity of burning, which, in turn, is strongly affected by season and soil moisture (Blaisdell and Mueggler 1956b).

With the exception of occasional sprouting by threetip (*A. tripartita*) and silver (*A. cana*), sagebrushes are nonsprouters, so are easily killed by fire. Absence of sagebrush on many areas is an indicator of past burns. Since associated shrubs are able to sprout, at least to some degree, it is significant that sagebrush has been able to maintain a prominent position in the vegetation (fig. 10B).

It is apparent that response to burning within each class—grasses, forbs, or shrubs—is highly variable. If initial effects that are generally injurious to all species are ignored, the following classification, based on sprouting ability of shrubs and growth form of herbs, is fairly reliable for describing response of perennial species:

Severely damaged.—Shrubs that are unable to sprout, suffrutescent forbs, and fine bunchgrasses with densely clustered culms such as Idaho fescue and needle-and-thread.

Only slightly affected.—Coarse bunchgrasses, fine bunchgrasses with loosely clustered culms such as bluegrasses and squirreltail, forbs that are neither suffrutescent nor rhizomatous, shrubs with a limited sprouting habit.

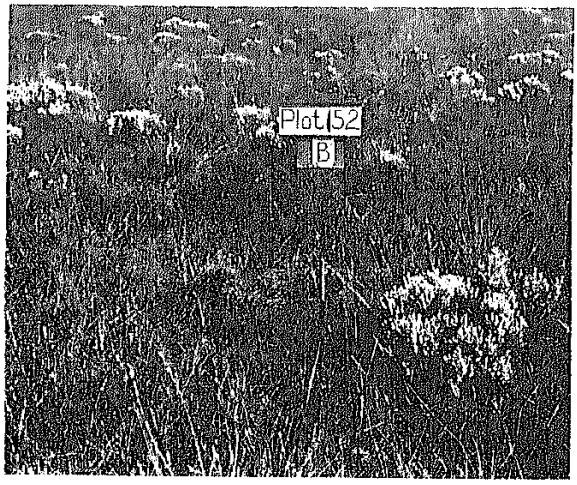
Considerably benefited.—Shrubs with strong sprouting habit, rhizomatous grasses, rhizomatous forbs.

For additional information on effects of burning on sagebrush-grass vegetation, see the review by Wright and others (1979).

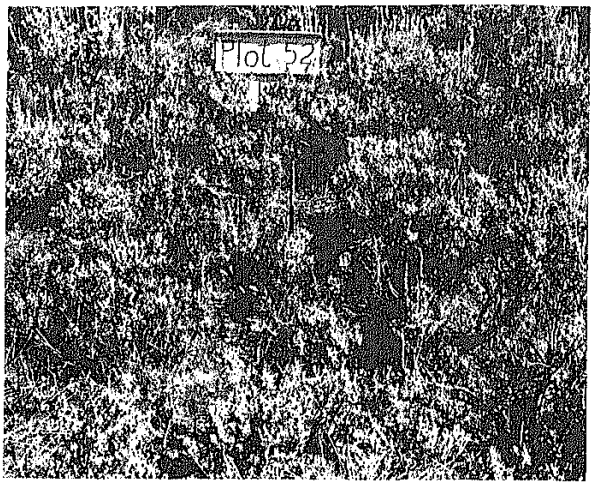
Since vegetal response is closely related to burn intensity, early spring or winter burns will be less injurious to most species than those in summer or fall when soil moisture is low and temperatures are high. Summer burns can be especially devastating to grasses and forbs because they destroy herbage before maturity (Blaisdell and Pechanec 1949; Pechanec and others 1954). Sagebrush, the usual target species, is readily killed by fire in all seasons at even light intensities.

Prescribed burning in winter or spring requires relatively dense vegetation and favorable burning conditions; consequently, it may be possible to burn only limited areas during these seasons (Beardall and Sylvester 1974; Neuenschwander 1980). Murray 1980,[1] however, has had considerable success with spring burning on the Upper Snake River Plains. His experience indicates the need for a period of warm, dry weather in early April to remove the winter snowpack and to dry the grass and forb litter. At this time, moisture content of sagebrush leaves and stems is usually low.

[1]Murray, R. B. Data on file. Dubois, ID: U.S. Department of Agriculture, Agricultural Research Service, U.S. Sheep Experiment Station; 1980.



A



B

Figure 10.—The same plot shown in figure 9. (A) 6 years after burning. Most of the shrubs are rabbitbrush and horsebrush sprouts from the original plants. (B) 30 years after burning. A fairly dense stand of sagebrush now dominates the plot despite conservative grazing management.

A burn in April 1977 was preceded by an unusually dry winter and followed by an exceptionally wet spring and summer. At the time of the burn, Idaho fescue, thickspike wheatgrass, and some forbs were beginning to turn green. By August shrub, grass, and forb production was 62, 714, and 48 lb/acre (70, 801, and 54 kg/ha) compared to 5,705, 300, and 85 lb/acre (6 392, 336, and 95 kg/ha), respectively, on the adjacent unburned site. The spring and summer of the second year were drier than normal, but production of Idaho fescue was 103 percent of that on the unburned area. Within 2 years, production of forbs on the burn increased from 57 to 181 percent of the unburned.

The advantage of spring burning appears to be the higher level of soil moisture that acts to protect the plants and provide moisture for immediate growth following burning. Incidence of bitterbrush sprouting can be as high as 90 percent. Individual bunchgrasses are seldom burned deep into the crown as often happens during late summer or fall. The moist soils are less susceptible to wind erosion, and rapid growth of the plants further acts to protect the soil from erosion. From an economic standpoint, spring burning is cheaper as it can be accomplished with fewer individuals and without firebreaks in some situations. A disadvantage of spring burning is the higher rate of sprouting for threetip sagebrush—10 percent as compared to less than 1 percent on fall burns.

Effects of fire on soils were reviewed by Mueggler (1976). Ordinarily, nutrients contained in vegetation are released slowly by decomposition of the plant litter; however, burning immediately releases these stored nutrients in the form of volatiles or ash. Nitrogen and sulfur are volatilized by combustion, at least partially, and may be lost to the system. Other nutrients are changed to water-soluble salts, which are immediately available for plant growth.

Change in nitrogen status of the soil is of special interest because of its influence on productivity. Direction and amount of change vary with individual situations. Apparently, nitrogen lost through volatilization is rapidly replaced by increased activity of nitrifying bacteria stimulated by nutrients released by fire. R. B. Murray and H. F. Mayland (1980, unpublished data) determined that nitrates were mineralized in the surface 0 to 2 inches (0 to 5 cm) of soil at a greater rate on a spring burn than on a similar unburned site.

Generally, such primary nutrients as phosphorus, potassium, calcium, magnesium, and a number of micronutrients are added to the soil as a result of burning. However, nutrients contained in the ash are highly water-soluble and may be removed from the site by leaching or surface flow until they are again tied up by vegetation or soil.

Removal of vegetation by fire increases the possibility for soil loss through wind and water erosion. The potential seriousness of such loss depends upon such factors as burn intensity, soil erodibility, topography, frequency of high-intensity wind and rain, and rapidity of vegetation reestablishment. Wind erosion, even on high-intensity burns, is often no more than redistribution of ash until stabilized by rainfall. Water erosion is generally not serious except where torrential storms happen to occur on steep slopes.

Guidelines for Use

The primary use of fire on sagebrush-grass ranges should be control of dense stands of sagebrush so that the more desirable species can increase. Usually the goal should be roughly consistent with the climax cover that can be attained in a particular habitat type or site. It is true that forage production on a fairly recent burn might surpass that on a similar area in climax condition because of replacement of sagebrush by perennial grasses and forbs. However, ranges that are naturally sagebrush-grass climax cannot be entirely freed of sagebrush for an indefinite period. Repeated burning, especially at close intervals, to maintain such a subclimax stage would probably result in eventual impoverishment of the soil and loss of desirable species.

Prescribed burning will seldom be possible or desirable in the dwarf sagebrush habitat types. For the most part, vegetation is too sparse to carry a fire except under extremely hazardous conditions. Furthermore, many of the dwarf species, especially black sagebrush (*A. nova*) and low sagebrush (*A. arbuscula*), are desirable forage plants for livestock and wildlife. Use of fire may be a

possibility in some deteriorated habitat types of low sagebrush, but experimental testing will be necessary before reliable prescriptions can be formulated.

Although numerous habitat types have been described in the tall sagebrush group, in the Intermountain area only five taxa are important from the standpoint of acreage involved and possibilities for prescribed burning: basin big sagebrush (*A. tridentata* ssp. *tridentata*), Wyoming big sagebrush (A. *tridentata* ssp. *wyomingensis*), mountain big sagebrush (*A. tridentata* ssp. *vaseyana*), threetip sagebrush (*A. tripartita* ssp. *tripartita*), and mountain silver sagebrush (*A. cana* ssp. *viscidula*). Habitat types of mountain silver sagebrush probably support sufficient vegetation to allow burning, but these must be studied further before burning can be recommended.

For all practical purposes, then, burning can only be prescribed for habitat types of threetip sagebrush, and basin, Wyoming, and mountain big sagebrushes. However, these represent some 60 percent of the total sagebrush area and include most of the situations where fire should or can be used as a management tool. Furthermore, sufficient experience is available to allow reliable guides for use of fire in these habitat types.

Burning as a range improvement measure should be implemented only after alternatives have been considered and a satisfactory plan has been developed and approved. Where, when, and how to burn should all be addressed—as well as followup management.

Where.—Sagebrush range should be burned only where all the following conditions prevail:

1. Soils are stable and slopes are less than 30 percent. Burning seriously increases the danger from erosion by removing protective cover for a considerable time. If topsoil blows or washes away, fertility will be lost, plant roots will be exposed, and a protective vegetal cover will be slow to reestablish.

2. Sagebrush is dense and forms more than a third of the plant cover. Scattered stands of sagebrush do not offer serious competition to grasses and forbs, so its removal allows little range improvement. Also, unless the grass understory is thick, sparse stands of sagebrush provide a scanty supply of fuel and usually cannot be burned except under extremely hazardous conditions.

3. Fire-resistant perennial grasses and forbs form more than 20 percent of the plant cover, or revegetation with desirable species is practicable. If perennial grasses and forbs are not present prior to burning, it will be necessary to establish a suitable cover through seeding.

4. Principal use of the area is livestock grazing or where it has been demonstrated that burning will not adversely affect conditions for wildlife. In addition to providing more forage for both livestock and wildlife, burning often creates improved wildlife habitat by increasing diversity and broadening the food base. It must be recognized, however, that many shrubs, including sagebrush, are necessary for wildlife and should not be destroyed on certain critical areas.

When.—Satisfactory burns can be achieved most consistently in early fall. At this time, damage to the nontarget species is tolerable, and weather conditions will generally allow successful burning. Seed of perennial herbaceous species and bitterbrush will have been disseminated by this time, and some may survive the burn to produce seedlings the following year. Preparation of fire lines and other arrangements are expensive, so burning should be accomplished before cool, moist weather arrives in the fall.

Early spring burning will kill sagebrush with minimum damage to other species because temperatures are relatively cool and moisture is relatively high. Timing is critical as conditions that allow burning seldom last for more than a few days. Also, use of fire may be restricted to small areas where sagebrush and other fuels are especially dense. Careful monitoring of fuels and weather, however, may allow successful burning in certain favorable situations. Suppression costs of spring burning are minimal.

Midsummer burning is generally not recommended because it causes maximum damage to perennial grasses. Furthermore, burning at this time increases the chance for serious wind and water erosion by lengthening the time of soil exposure to these elements.

How.—Detailed planning is a prerequisite for safe and successful burning. Local and Federal fire laws and regulations must be observed. Information on these an other matters relating to prescribed burning can be obtained form State and Federal land management agencies such as State Department of Lands or Forestry, Bureau of Land Management, and Forest Service. A burning permit is always required.

The plan should contain a description of the area to be burned, weather requirements and proposed time for burning, necessary preburn preparations including construction of firelines, details for carrying out the burn with a list of required men and equipment, and a comprehensive management plan showing how the burned area will be treated in subsequent years in conjunction with adjacent lands.

Adequate firelines must be construeted to prevent escape of the fire. Wright and others (1979)—based on experience of Peehanec and others (1954), Ralphs and others (1976), and Davis (1976)—recommend surrounding the area to be burned with a bulldozed break 10 to 12 ft (3 to 3.7 m) wide. This would then be expanded to about 200 ft (60 m) on the leeward sides by strip backfiring during the morning hours when wind is 5 to 8 mi/h (8 to 13 km/h) and relative humidity is about 40 percent. A pumper is used to extinguish the backfire when the desired width is obtained. A less flexible but perhaps safer method is to construct a second cleared line parallel to, but about 200 ft (60 m) inside, the first. Vegetation between the two lines is then removed by progressive backfiring (Pechanec and others 1954). Backfiring is a critical part of prescribed burning, and all possible precautions should be taken. The main area to be burned should be touched off when air temperature is above 75° F (24° C), relative humidity is 15 to 20 percent, and wind is 8 to 15 mi/h (13 to 24 km/h). Spring burning, however, may require different criteria.

Techniques now in developmental stage may eliminate the undesirable effects of bulldozing firelines (Davis 1976; Ralphs and others 1976). One possibility is the use of a large propane burning unit mounted on a trailer. Vegetation can be burned when moisture is high, and several strips can be burned to achieve the desired width. Another possibility is to spray the proposed firebreak with a contact herbicide while the vegetation is green. Subsequent burning of the sprayed vegetation should produce an adequate fireline. However, such methods cannot be recommended for general use without further study. The Intermountain Region of the Forest Service is testing a new method for starting prescribed fires (USDA Forest Service 1980) that involves a helicopter for dispensing ignited gobs of jelled fuel. This holds much promise for effecting future burning prescriptions.

Considerable effective burning can be accomplished without the use of prepared firelines, providing natural firebreaks are used. Fire will seldom carry in dwarf sagebrush habitat types, so patches of big sagebrush growing in swales surrounded by such fire-resistant vegetation can often be burned safely without preparing firelines. Similarly, early spring burning can often be accomplished with minimal use of prepared firelines (Wright and others 1979).

Management after burning.—Proper grazing management following burning is essential. Even accidental burns may be beneficial if grazing is properly managed afterward. On the other hand, anticipated results for the best prescriptions may be seriously modified if destructive grazing practices are allowed.

Most burns should be completely protected from livestock grazing for at least one and possibly two growing seasons. Only a small amount of forage is produced the first year, and grazing may cause serious damage to soil and desirable perennials. Despite the apparent abundance of green herbage, most plants are low in vigor and will be further weakened or destroyed by grazing. Furthermore, grazing will disturb the inadequately protected soil and allow increased water and wind erosion.

Protection through the second growing season will allow restoration of vigor and the typical heavy seed production of perennial grasses and forbs. However, after seed dissemination, light grazing may serve a useful purpose in helping to plant the seed.

On areas where cheatgrass is abundant, special measures may be necessary to prevent recurrent fires, which would be devastating to perennial grasses and forbs already weakened by burning. Also, areas with only a poor stand of desirable perennials prior to burning will probably require seeding to provide satisfactory forage production and delay return of sagebrush or other unwanted species.

Accidental burns should, of course, be protected and managed in the same way as prescribed burns. If this is done, damage will be minimized and what at first appears to be a tragedy may actually result in significant improvement.

SPRAYING

Control of sagebrush with herbicides became common in the early 1950's when it was demonstrated that 2,4-D, a plant growth regulator, could effectively kill big sagebrush (Evans and others 1979). Although numerous other chemicals such as 2,4,5-T and Picloram were developed concurrently or in subsequent years, 2,4-D has generally been most effective and most economical for sagebrush control and so has received widespread use. It has not been proven toxic to humans or animals, is readily degradable, and is approved by the Environmental Protection Agency for use on sagebrush rangelands.

Because effective control of big, low, black, silver, threetip, and alkali sagebrushes with 2,4-D has been reported (Pechanec and others 1965; Blaisdell and Mueggler 1956a; Eckert and Evans 1968), it is assumed that all sagebrushes are susceptible to this chemical. Results generally indicate that sagebrush is most vulnerable in the spring when it is actively growing. This corresponds roughly to the period when small bluegrasses come into head until they are drying and losing their green color.

Satisfactory results can usually be obtained with 2 lb acid equivalent of a low-volatile ester formulation of 2,4-D per acre (2.25 kg/ha). (Incidentally, this treatment will also be effective in controlling wyethia [*Wyethia amplexicaulis* and *W. helianthoides*], an undesirable forb often associated with mountain big sagebrush [Mueggler and Blaisdell 1951].) Approximately 5 gal of water or 3 gal of diesel oil/acre (47.5 liters water or 28.5 liters diesel/ha) will provide an adequate carrier. Although some range managers prefer diesel oil, it is doubtful that any increase in effectiveness justifies the additional cost. In dense stands of sagebrush, a greater volume of spray material may be needed to insure proper coverage. Low rabbitbrush (*Chrysothamnus viscidiflorus*), lanceleaf rabbitbrush (*C. viscidiflorus* ssp. *lanceolatus*), and broom snakeweed (*Gutierrezia sarothrae*) can be killed along with sagebrush by increasing the application rate of 2,4-D to 3 lb/acre (3.4 kg/ha) and spraying during the latter part of the effective season for killing sagebrush (Eckert and Evans 1968; Laycock and Phillips 1968; Pechanec and others 1965).

Application of the spray solution can be made with ground rigs, fixed-wing aircraft, or helicopters. Use of ground equipment is limited to relatively level, rock-free areas, whereas airplanes and helicopters can apply the herbicide to nearly all sites. Helicopters allow safe, low-level flying at reduced speeds and permit precise application to designated areas. Spraying should be accomplished when winds are less than 8 mi/h (13 km/h) and temperature is below 70° F (21° C). Such conditions normally occur in early morning and reduce the problems associated with evaporation, volatilization, drift, and air turbulence.

Because of the effects of 2,4-D on species associated with sagebrush, composition of the vegetation must be carefully considered. Perennial grasses are seldom damaged, so they can be expected to increase as a result of reduced competition from sagebrush. However, many desirable perennial forbs and shrubs are severely damaged by spraying, and this damage must be evaluated in relation to anticipated benefits.

Some forbs are particularly vulnerable to 2,4-D, but effects have been largely ignored by many range scientists in their efforts to increase production of grass. Nevertheless, effects on forbs of spraying with 2,4-D have been observed in Idaho (Blaisdell and Mueggler 1956a), Nevada (Eckert and others 1972; Laycock and Phillips 1968), Oregon (Miller and others 1980), and Wyoming (Hurd 1955). Evaluation of response in Idaho has been expanded to include observations from the other States (table 2). Consistency of results for the various situations lends confidence to the assigned damage ratings.

Among those forbs moderately or severely damaged by spraying are such important forage species as arrowleaf balsamroot (*Balsamorhiza sagittata*), milkvetch (*Astragalus stenophyllus*), one flower sunflower (*Helianthella uniflora*), several lupines (*Lupinus* spp.), and bluebell (*Mertensia oblongifolia*). Important forage plants not seriously damaged by 2,4-D include hawksbeard (*Crepis acuminata*), geranium (*Geranium viscosissimum*), penstemon (*Penstemon radicosus*), and groundsel (*Senecio integerrimus*). Groundsel, however, is a species that matures and dries early in the growing season, and it might be damaged by early spraying. Such poisonous species as deathcamas (*Zygadenus paniculatus*), halogeton (*Halogeton glomeratus*), and orange sneezeweed (*Halenium hoopesii*) are severely damaged by 2,4-D, whereas larkspurs (*Delphinium depauperatum* and *D. glaucescens*) are unharmed by spraying rates normally used for sagebrush control.

Table 2.—Mortality[1] of forms on areas sprayed with 2,4-D to control big sagebrush (largely from Blaisdell and Mueggler 1956)

Species	Mortality	Species	Mortality
Achillea millefolium	Unharmed	*Galium boreale*	Unharmed
Agastache urticifolia	Light	*Geum triflorum*	Heavy
Agoseris ssp.	Moderate	*Geranium viscosissimum*	Unharmed
Antennaria microphylla	Light	*Helianthella uniflora*	Heavy
Aplopappus sp.	Unharmed	*Linum lewisii*	Unharmed
Arenaria congesta	Unharmed	*Lithospermum ruderale*	Moderate
Arnica fulgens	Light	*Lupinus caudatus*	Heavy
Aster foliaceus	Unharmed	*Lupinus laxiflorus*	Heavy
Aster scopulorum	Moderate	*Lupinus leucophyllus*	Moderate
Astragalus convallarius	Unharmed	*Lupinus sericeus*	Heavy
Astragalus miser praeteritus	Unharmed	*Mertensia oblongifolia*	Heavy
Astragalus salinus	Unharmed	*Opuntia polyacantha*	Unharmed
Astragalus stenophyllus	Heavy	*Penstemon radicosus*	Light
Balsamorhiza sagittata	Heavy	*Penstemon* spp.	Heavy
Calochortus macrocarpus	Unharmed	*Perideridia gairdneri*	Unharmed
Castilleja spp.	Heavy	*Phlox canescens*	Light
Comandra umbellata	Light	*Potentilla gracilis*	Heavy
Crepis acuminata	Unharmed	*Potentilla* spp.	Heavy
Delphinium depauperatum	Unharmed	*Rumex* sp.	Unharmed
Delphinium glaucescens	Unharmed	*Senecio integerriumus*	Light
Erigeron corymbosus	Light	*Solidago* sp.	Unharmed
Eriogonum heracleoides	Light	*Trifolium macrocephalum*	Heavy
Eriogonum ovalifolium	Unharmed	*Viola* spp.	Unharmed
		Zigadenus paniculatus	Heavy

[1]Ratings: unharmed; light, 1 to 33 percent kill; moderate, 34 to 66 percent kill; heavy, 67 to 100 percent kill.

Temporary damage to shrubs by spraying is often severe. Aerial portions of snowbrush (*Ceanothus velutinus*), downy rabbitbrush (*Chrysothamnus viscidiflorus* ssp. *puberulus*), aspen (*Populus tremuloides*), chokecherry (*Prunus virginiana*), snowberry (*Symphoricarpos oreophilus*), and willows are easily damaged by 2,4-D. Although these species sprout vigorously, production of herbage and seed is greatly reduced for several years. As with burning, serviceberry (*Amelanchier alnifolia*) is severely damaged by spraying because little sprouting occurs, and, therefore, reestablishment of this desirable species may be extremely slow. Bitterbrush (*Purshia tridentata*), a valuable forage species for both livestock and big game, is apparently resistant to spraying provided the stand is mature. Young plants, however, are especially susceptible to 2,4-D, according to Hyder and Sneva (1962). These investigators observed considerable mortality in bitterbrush following spraying for sagebrush control, but concluded that damage is minimal when spraying occurs during the period between appearance of new leaves and initiation of twig elongation and flowering. Sagebrush will be killed effectively during this period. Shrubby cinquefoil (*Potentilla fruticosa*), pricklypear (*Opuntia polycantha*), and horsebrush (*Tetradymia canescens* var. *inermis*) are apparently unharmed by 2,4-D.

The differences in response of various associated forbs and shrubs indicate a need for careful consideration of vegetal composition when planning range improvement by spraying with 2,4-D to control sagebrush. Indiscriminate spraying may destroy many desirable species and allow their replacement by inferior species not damaged by 2,4-D, or by invasion of undesirable annuals. In such cases, seeding may be necessary to insure satisfactory results. Also, total forage production may be decreased for several years. This is especially probable on sheep ranges where forbs supply a large part of the forage, on big-game ranges where tops of shrubs are killed, or on sage grouse (*Centrocercus urophasianus*) habitat where sagebrush and forbs supply a major portion of their diet.

Managers should know the improvement potential of ranges they plan to treat; consequently, they must recognize habitat types or range sites and relative condition. This is essential because the greatest response to sagebrush control will usually occur on high-potential sites in fair condition, where a well-distributed stand of grass can increase and replace the sagebrush. Productive potential of dwarf sagebrush habitat types is seldom great enough to justify sagebrush control. Similarly, expected

MECHANICAL REMOVAL

Several mechanical methods for sagebrush control have been successfully used during the past 50 years. These include plowing or disking, root cutting, beating or shredding, railing, and chaining (Pechanec and others 1965; Plummer and others 1968; Parker 1979). Choice among these methods will depend upon such factors as size and density of the sagebrush, need to destroy or preserve understory vegetation, size of area to be treated, rockiness and other characteristics of the site, and availability of equipment.

Plowing or Disking

Where there is not an adequate understory of desirable perennials, plowing or disking will destroy the sagebrush and prepare a good seedbed for revegetation. The most effective implements are the wheatland plow, offset disk, and brushland plow. The latter has been most popular, particularly on rocky areas, because pairs of disks are independently spring-controlled so that they can rise over obstructions without excessive breakage. Plowing to a depth of a few inches should be sufficient.

Several types of root-cutting equipment are available commercially. A common design consists of one or more V-shaped blades mounted on a heavy frame. When these are pulled through the soil at 4 or 5 inches (10 or 12 cm) deep, most of the vegetation is killed, but disturbance to the soil surface is minimal. This treatment may not provide as good a seedbed as disking, but the erosion hazard is less. Root cutting must be confined to relatively rock-free areas or breakage may be excessive. Seeding is necessary to restore a satisfactory stand of desirable species.

Beating or Shredding

A wide variety of mechanical equipment has been developed to destroy the aboveground portions of plants by cutting, beating, or shredding and leaving a coarse layer of litter on the ground surface. Although such treatments can generally be effective for sagebrush control, cost is relatively high because the heavy equipment required is expensive to buy and operate. Rocks or other obstructions will cause excessive breakage. Herbaceous vegetation suffers only minimal damage, so it can immediately take advantage of reduced competition. This treatment may miss or cause little damage to small sagebrush plants, and such undesirable shrubs as rabbitbrush and horsebrush will sprout profusely.

Railing

Uprooting or breaking off sagebrush by dragging a heavy rail across the stand is one of the oldest methods of control. It was originally used to clear lands for farming, but has been successfully used on many range areas. Railing is particularly effective on level, rock-free sites where the sagebrush is large and brittle. As with shredding, kill of small sagebrush plants or sprouting shrubs is poor. Damage to understory grasses and forbs is slight.

Chaining

Anchor chaining is an effective, economical, and widely applicable method for thinning stands of big sagebrush and releasing grasses and forbs. It was originally developed for eliminating stands of pinyon and juniper, but has also been used successfully for controlling many other woody species. Chains about 200 ft (60 m) in length, with links weighing between 25 and 90 lb (11 and 40 kg) each, are pulled between two tractors. This will create a swath about 100 ft (30 m) wide. Chaining is adapted to varied terrain and is especially useful on areas too rocky or steep for other mechanical methods.

If an adequate understory is not present, a modified chain may be used to prepare a good seedbed. This is accomplished by constructing a chain with 18-inch (45-cm) lengths of light rail welded to each link. This type of chain will destroy more sagebrush and will also allow covering of introduced seed. Normally, twice-over chaining in opposite directions, with broadcast seeding between the two chainings, will produce desired results.

General Considerations

Although mechanical sagebrush control and revegetation may be successfully carried out on some low and alkali sagebrush habitat types, such measures should generally be avoided on dwarf sagebrush sites. These normally are areas of shallow soils with low productive potential, and satisfactory revegetation is often difficult to achieve. Furthermore, this existing stand of sagebrush is often of considerable value to wildlife.

On areas where control is in effect, management should encourage continued maximum production of forage for livestock and wildlife consistent with soil protection. Grazing use should be designed to discourage the return of sagebrush, and thus avoid the need for frequent control measures. As with burning and spraying, best results are obtained from mechanical sagebrush control if sufficient protection from grazing is provided to allow residual or seeded grasses and forbs to take advantage of the reduced competition. No grazing should be allowed for at least a year after treatment, and on seeded areas, protection should be continued for two growing seasons to allow establishment of the new plants.

BIOLOGICAL CONTROL

Control of pricklypear (*Opuntia stricta* and *O. inermis*) in Australia by the phycitid moth (*Cactoblastis cactorum*) introduced from South America, and control of St. Johnswort (*Hypericum perforatum*) in the western United States by the European chrysomelid (*Chrysolina gemellata*) are outstanding examples of biological control of undesirable plants (Huffaker 1957). These and other successes in this field offer some hope that sagebrush may similarly be controlled by biological agents. As with burning, spraying, and mechanical removal of sagebrush, the aim of biological control is not eradication but reduction to a tolerable level. Insects, small mammals, and large herbivores are all possibilities for biological control of sagebrush. Although these control agents hold considerable promise for the future, much research and testing will be necessary before practical use can be recommended.

Insects

Although a wide variety of insects inhabit sagebrush-grass communities, only a few have caused significant damage to sagebrush. One of these is a moth (*Aroga websteri*) whose larvae feed exclusively on foliage of big sagebrush and such related species as low, black, and silver sagebrushes. Gates (1964) reported that in Oregon during 1962, most of the sagebrush on 10,000 to 15,000 acres (4 000 to 6 000 ha) was killed by this insect, and during the following year some 12 million acres (5 million ha) were infested. Degree of infestation and effects on the sagebrush are highly variable; however, young, vigorous stands on productive sites seem to be most resistant. Apparently, *Aroga* populations are controlled by parasites and do not remain at

peak levels for more than a year to two.

A leaf-feeding beetle (*Trirhabda pilosa*) appears to have a high potential for killing sagebrush, but few outbreaks have been noted. Severe damage by this insect to big sagebrush in British Columbia was observed by Pringle (1960) during 1956-58, but the high infestation was short-lived. A similar infestation of *Trirhabda attenuata* on threetip sagebrush in Wyoming was reported by Fisser and Lavigne (1961).

The insects discussed above are native to sagebrush-grass vegetation. Apparently, an ecological balance is maintained in which damage to the sagebrush is minimal. However, when insect population explosions are periodically triggered by favorable environmental factors, sagebrush can be severely damaged. The result is similar to that caused by natural fires. Although sagebrush may be destroyed on sizable areas, it eventually becomes reestablished on sites to which it is adapted. In any event, it seems futile to attempt biological control of sagebrush with these insects until more is known about their population dynamics, especially triggering mechanisms.

Small Mammals

Like insects, numerous small mammals are native to sagebrush-grass ranges. For the most part, they have not caused serious damage to sagebrush. However, voles (*Microtus* spp.) are known to girdle and kill sagebrush over sizable areas. Mueggler (1967) observed an outbreak of voles during 1962-64 in southwestern Montana, which caused damage to a number of shrubs including big and silver sagebrush, sumac (*Rhus trilobata*), bitterbrush, mountain mahogany (*Cercocarpus ledifolius*), and serviceberry (*Amelanchier alnifolia*). Sagebrush was severely damaged by bark stripping, and more than 80 percent of the stand was killed in some areas. A similar population explosion of longtailed voles (*Microtus longicaudus*) in 1969 caused considerable mortality to big sagebrush over extensive areas in Utah (Frischknecht and Baker 1972). Highest kills of sagebrush occurred on areas where herbaceous vegetation was thick and a snow cover persisted throughout the winter.

Although voles are capable of thinning or destroying stands of sagebrush, sufficient information is not available to allow their use for biological control. They are natives of the sagebrush-grass ecosystem, and normal populations apparently have little impact. Factors responsible for population eruptions and methods of inducing them will have to be known before voles or other small mammals can be effectively managed for biological control of sagebrush.

Large Herbivores

During severe winters, stands of sagebrush have been decimated by high concentrations of deer and elk. Likewise, domestic livestock have destroyed sagebrush on heavily used areas near waterholes, salt grounds, and winter feedyards. However, control of sagebrush on large range areas by such concentrated use is neither possible nor desirable.

The most successful control of sagebrush by large herbivores has been with sheep. At the U.S. Sheep Experiment Station in eastern Idaho, heavy late-fall grazing by sheep improved poor-condition range by reducing threetip sagebrush some 20 percent and allowing a 30 percent increase in grasses and forbs (Laycock 1967). In central Utah, late-fall and winter grazing of crested wheatgrass pastures with sheep reduced the size of big sagebrush plants and limited their reproduction (Frischknecht and Harris 1973).

To date, only grazing of sheep during the late fall or winter has shown significant promise for biological control of sagebrush. Grazing by goats is another possibility, but it has not been adequately tested. For the most part, biological control of sagebrush is not a practical substitute for burning, spraying, or mechanical removal at the present time.

Frequency of Control Measures

Because reestablishment of sagebrush is hindered by competition from other species, management following control should attempt to create and maintain a good stand of perennial grasses and forbs. Ranges in poor condition should usually be seeded to desirable species and all should be grazed conservatively. However, long-term studies on sagebrush control by burning (Harniss and Murray 1973) and chemicals (Sneva 1972) indicate that brush will eventually return to big sagebrush habitat types regardless of management. Consequently, there will be a need for planning sagebrush control on a continuing basis, especially in mountain big sagebrush habitat types. In addition to competing vegetation and grazing practices, the length of time between control measures is influenced by undefined weather variables (perhaps moisture patterns) that favor sagebrush seedling survival and establishment. Seed production of sagebrush before and after control may also be a factor in rapidity of its reestablishment.

At any rate, control measures such as burning or spraying apparently do not have serious long-term impacts on either vegetation or soil. If necessary, sagebrush control at 20-year intervals should be tolerable for most situations.

Revegetation

Vegetation on extensive areas of sagebrush-grass range has been depleted by past abuses. Where original cover of perennial grasses and forbs has been mostly destroyed, sagebrush and other shrubs with low palatability have increased, and often such undesirable annuals as cheatgrass, halogeton, and medusahead have invaded. In such situations neither complete protection nor conservative grazing can restore a desirable vegetal cover within a reasonable period because a seed source of desirable species is lacking and competition from the undesirable plants is severe. For example, Holmgren (1976) observed little or no improvement in depleted sagebrush-grass vegetation on several sites in Nevada after 38 years of protection or continued grazing. Consequently, removing competing vegetation, especially sagebrush, and seeding with desirable species of grasses, forbs, and shrubs is often the only satisfactory method of restoration.

Much has been learned about seeding western rangelands during the past 50 years, and useful guides were provided by Plummer and others (1955) on where, how, when, and what to seed, as well as proper management of seeded ranges. Keller (1979) synthesized similar information in a comprehensive literature review for the sagebrush-grass ecosystem. He emphasized selection of adapted species and proper methods including reduction of competition, seedbed preparation, application of seed, proper covering, and grazing management.

Hull (1974) reexamined 2,450 plots on depleted sagebrush rangelands in southern Idaho 20 to 40 years after seeding. Fairway and desert crested wheatgrasses (*Agropyron cristatum* and *A. desertorum*) were the most successful species on dry sites, whereas intermediate (*A. intermedium*) and pubescent (*A. tricophorum*) wheatgrasses were superior on the moist sites. Russian wildrye (*Elymus junceus*) was fairly well-

adapted, especially to moderately saline soils. Western (*A. smithii*) and Siberian (*A. sibiricum*) wheatgrasses produced some good stands, but were not consistently successful. Other species exhibiting varying degrees of success were thickspike, tall, and bluebunch wheatgrasses (*A. dasystachyum*, *A. elongatum*, and *A. spicatum*), smooth brome (*Bromus inermis*), big, bulbous, and Sandberg bluegrasses (*Poa ampla, P. bulbosa*, and *P. sandbergii*), and arrowleaf balsamroot (*Balsamorhiza sagittata*). Control of competing vegetation and adequate covering of seed was necessary to obtain good stands.

In general, stands of adapted species are closely related to rate of seeding, although initial differences largely disappear with time. On the Upper Snake River Plains, Mueggler and Blaisdell (1955) compared five rates of seeding crested wheatgrass: 2, 4, 8, 12, and 24 lb/acre (2.2, 4.5, 9.0, 13.5, and 27.0 kg/ha). The three highest rates produced the best stands during the first 3 years, but after 6 years yield of all stands was similar. In other southern Idaho studies, Hull and Holmgren (1964) reported that after 10 years yields from plots seeded at rates varying from 1 to 40 lb/ acre (1.1 to 45.0 kg/ha) were approximately the same. In Utah, however, plots of crested and pubescent wheatgrass that were seeded lighter than 4 lb/acre (4.5 kg/ha) were not producing at full potential even after the ninth growing season (Cook and others 1967). For the most part, seeding wheatgrasses at the rate of about 8 lb/acre (9.0 kg/ha) should be adequate to produce a satisfactory stand within a reasonable length of time.

Most of the early effort in revegetation of sagebrush-grass ranges was oriented toward increasing quantity and quality of livestock forage and providing better watershed protection. Consequently, establishment of a good stand of palatable, perennial grass was the usual objective, and this often resulted in stands of crested or other exotic wheatgrasses. With the recognition of the limited value of single species and the risks involved from such factors as insects, disease, and drought, more and more attention was given to mixtures that would provide better wildlife habitat, improve esthetics, include legumes for nitrogen fixation, and provide better nutritional balance for both livestock and wildlife.

From about 1960, increasing emphasis has been placed on the use of shrubs in mixtures for range revegetation. Selection and propagation studies have demonstrated that a number of native and exotic species can be successfully established within most sagebrush-grass communities (Monsen and Christensen 1975). Species selected for their forage and cover values, productivity, adaptability, and ease of establishment include: antelope bitterbrush (*Purshia tridentata*), desert bitterbrush (*P. glandulosa*), Martin ceanothus (*Ceanothus martinii*), cliffrose (*Cowania mexicana*), blueberry elder (*Sambucus cerulea*), green ephedra (*Ephedra viridis*), rubber rabbitbrush (*Chrysothamnus nauseosus*), fourwing saltbush (*Atriplex canescens*), winterfat (*Ceratoides lanata*), and, of course, several sagebrushes. Considerable variability among separate collections, ecotypes, and subspecies has been observed, and these differences are being used by personnel of the Intermountain Station's Shrub Sciences Laboratory at Provo, Utah, to promote the development of superior traits. Already, the forage qualities of various shrubs have been markedly improved through selection and propagation of palatable and productive collections.

Sagebrushes are especially aggressive, productive, and persistent. Such plants are good candidates for improvement through increased forage yield and quality (Welch and McArthur 1979a). Sagebrushes vary in growth rate and form (McArthur and Welch 1982), in protein content (Welch and McArthur 1979b), and in other qualities. With these variations they make good material for genetic improvement through selection alone or selection combined with hybridization. Improvement in both forage value and soil-binding capability should be possible. Nevertheless, even the most improved sagebrush may fall short as livestock forage because of the grazing preferences of particular animals, especially cattle. Wise management of sagebrush-grass ranges, therefore, may entail maintaining productive natural sagebrush stands, seeding sagebrush, or eradicating it, depending upon the management objective (McArthur and Plummer 1978).

Although the work of Plummer and others (1968) was primarily directed at restoration of big-game ranges, their guidelines, which follow here, are appropriate for revegetation of almost all areas in the sagebrush-grass ecosystem being managed for multiple uses and values.

1. **Change in plant cover must be determined, by rational criteria, to be necessary and desirable.** The usual goal of developing a productive stand of desirable shrubs, grasses, and forbs can sometimes be achieved by selective plant control or change in grazing management. However, at least one desirable shrub and 10 desirable herbaceous plants per 100 ft^2 (9 m^2) should be present. Revegetation may be necessary to provide browse for winter or succulent forage for early spring. Watershed considerations are also important, and seeding grasses and forbs may be necessary for soil stabilization.

2. **Terrain and soil must be suitable for the selected restoration.** Deep, fertile soils on level to gently sloping land are preferred sites for seeding. Shallow, rocky, or infertile soils seldom justify expensive restoration measures. Excessive amounts of soluble salts often preclude successful revegetation. Treatment of steep slopes is difficult and expensive, and may not be worthwhile unless the need for erosion control is critical.

3. **Precipitation must be adequate to assure establishment and survival of planted species.** Average annual precipitation usually should be 10 inches (25 cm) or more if seeding is part of the restoration project. Where precipitation is near this limit, only the more drought-resistant species such as crested wheatgrass, Russian wildrye, bluestem wheatgrass, and dryland alfalfa should be seeded. Existing vegetation is a good indicator of the moisture situation.

4. **Competition from existing vegetation must be light enough to allow successful establishment of seeded species.** Thick stands of big sagebrush and annuals such as cheatgrass must be at least partially eliminated by some of the sagebrush control methods already discussed. Seeding directly into existing vegetation (interseeding) may also be practiced successfully if the drill is equipped with scalpers to clear a swath of sufficient width to decrease competition.

5. **Only adapted species and strains should be planted.** Species used for seeding must be able to establish and maintain a suitable stand of vegetation on the selected site. Probability of success will be increased by using species with demonstrated adaptability and seed from an environment similar to that of the area proposed for seeding.

6. **Mixtures of plant types rather than single species should be seeded.** Terrain and climatic factors are often variable. Seeding mixtures will offer the best chance of including suitable species for the diverse sites, and will usually result in a superior ground cover for control of erosion. Also, mixtures of grasses, forbs, and shrubs will better supply the nutritional needs of grazing animals. If seeds of certain species are in short supply, they can be hand-seeded on special sites to which they are best adapted.

7. **Sufficient seed of acceptable purity and viability should be seeded to insure a satisfactory stand.** Too heavy seeding is needlessly expensive, but skimping may jeopardize establishment of a good stand. Normally, 8 to 20 lb/acre (9.0 to 22.5 kg/ha) of the total seed mixture will be sufficient. Rates at the lower end of this scale are usually adequate for drilling, whereas the higher rates will be necessary if seed is broadcast. The required rate will also depend on species and quality of the seed. Good fill of recently collected seed is a good indicator of high quality if laboratory tests are not possible. Seeding rates should be increased if purity or viability is poor.

Dormancy of most seeds can be broken by stratification—subjecting them to temperatures between 32° and 40° F (0° and 4.4° C) for a period of 6 to 20 weeks in moist sand, peat moss, or newspaper. Dormancy will be naturally broken if seeds are planted in fall or winter. For some shrubs, treatment with thiourea or scarification with sulfuric acid or mechanical abrasion will help to overcome dormancy.

8. **Seed must be covered.** A light covering of soil, usually one-fourth to one-half inch (0.6 to 1.2 cm), will be sufficient. Drills can be set at the required depth, and chaining or pipe harrowing will usually provide adequate covering following broadcasting without burying the seed too deeply.

9. **Seeding or planting should be done in the season that promises best conditions for plant establishment.** Seeding is the usual means of establishing grasses, forbs, and a few shrubs. However, some shrubs can be propagated most satisfactorily by transplanting, usually in the spring. Direct seeding in late fall and throughout the winter, climate permitting, will usually be preferable for most species.

10. **Revegetated areas must be properly managed.** Livestock should be excluded until new plants are well established, and thereafter grazing should be regulated so that a vigorous stand can be maintained. Control may sometimes be necessary to prevent damage from big game. However, if treated areas are large, damaging concentrations will usually be avoided. Newly revegetated areas are also subject to damage from rabbits, rodents, and insects, but several effective control measures are available.

These general revegetation guides should be adapted to peculiar environments and specific objectives of areas selected for treatment. For revegetating a big sagebrush habitat type, Plummer and others (1968) recommend removal of sagebrush competition by anchor chaining, controlled burning, or spraying with 2,4-D. Seeding can be accomplished by aerial broadcasting or by using the rangeland drill. Anchor chaining is economical and effective for covering broadcast seed. If chaining is used as the method for sagebrush control, seed can be applied between the two chainings made in opposite directions. A suggested seed mixture for areas with approximately 10 inches (25 cm) annual precipitation includes the following:

	Lb/acre	*kg/ha*
Fairway crested wheatgrass (*Agropyron cristum*)	3.0	3.3
Standard crested wheatgrass (*A. desertorum*)	2.0	2.2
Bluebunch wheatgrass (*A. spicatum*)	.5	.6
Bluestem wheatgrass (*A. smithii*)	.5	.6
Intermediate wheatgrass (*A. intermedium*)	.5	.6
Pubescent wheatgrass (*A. tricophorum*)	.5	.6
Russian wildrye (*Elymus junceus*)	1.0	1.1
Alfalfa-Rambler, Nomad, or Ladak (*Medicago sativa*)	1.0	1.1
Arrowleaf balsamroot (*Balsamorhiza sagittata*)	.5	.6
Fourwing saltbush (*Atriplex canescens*)	1.0	1.1
Rubber rabbitbrush (*Chrysothamnus nauseosus*)	.5	.6
Total	11.0	12.4

For areas of higher precipitation such as habitat types of mountain big sagebrush, standard crested wheatgrass can be omitted, and Utah sweetvetch (*Hedysarum boreale* var. *utahensis*) and small burnet (*Sanguisorba minor*) can be added. Such shrubs as antelope bitterbrush, desert bitterbrush, cliffrose, Utah serviceberry (*Amelanchier utahensis*), and winterfat, can also be included in the mixture or seeded in special areas. Other grasses and forbs that may be substituted for herbaceous species in the mixture are bottlebrush squirreltail (*Sitanion hystrix*), Great Basin wildrye (*Elymus cinereus*), Indian ricegrass (*Oryzopsis hymenoides*), Siberian wheatgrass (*Agropyron sibericum*), Lewis flax (*Linum lewisii*), sicklepod milkvetch (*Astragalus cicer*), and yellow sweetclover (*Melilotus officinalis*). Improved varieties of many of these species have been developed and should be used where appropriate.

In southern Idaho, Monsen (1981, unpublished manuscript) drilled many of the above species into a depleted alkali sagebrush (*Artemisia longiloba*)/Idaho fescue (*Festuca idahoensis*) habitat type of untreated areas as well as those on which sagebrush was controlled by burning and chaining. Good stands resulted from a mixture of slender (*Agropyron trachycaulum*), crested, and intermediate wheatgrasses, Russian wildrye, alfalfa, Lewis flax, and small burnet on burned and chained areas. But failures resulted from drilling directly into untreated stands of sagebrush.

Because of the wide variation in sagebrush sites needing revegetation, soil and climatic factors should be considered before restoration is attempted so that allowances can be made for peculiar conditions. And because natural vegetation is a reliable integrator of environmental factors, classification by habitat types provides a useful tool for evaluating site potential, formulating adequate prescriptions, and extrapolating successful experiences from one area to another.

Grazing

INTENSITY AND SEASON

Although the influence of grazing may be exerted in many ways—trampling, fertilizing the soil, disseminating and planting seed—the most obvious influence is that of reducing the

volume of herbage and the area of photosynthetic surface (Ellison 1960). Because of this, many studies have attempted to evaluate the influence of grazing by clipping herbage to various degrees at different times during the growing season. Although clipping does not simulate grazing exactly, it can be a useful tool when applied with judgment in connection with studies of actual grazing.

Bluebunch wheatgrass (*Agropyron spicatum*), an important forage plant on many western ranges, has received considerable attention. Hanson and Stoddart (1940) observed that heavily grazed plants of bluebunch wheatgrass were smaller, produced fewer seeds, and had a markedly reduced root system. Stoddart (1946), in a study on this species in northern Utah, reported that severe clipping to heights of 1 and 2 inches (2.5 and 5.0 cm) reduced yield the following year and, except for very early spring and fall clipping, caused high mortality. In Montana, Mellvanie (1942) showed that repeated close clipping during active growth strongly reduced carbohydrate storage in the roots and stem bases of bluebunch wheatgrass. Also in Montana, Heady (1950) concluded that clipping this grass only once to 6 inches (15 cm) at the flowering stage would not allow its maintenance. In further studies with this species on the Snake River Plains of eastern Idaho, Blaisdell and Pechanec (1949) reported that clipping to ground level at any date, except after dormancy in the fall, reduced leaf height, flower stalk numbers, and herbage production the following year. Arrowleaf balsamroot (*Balsamorhiza sagittata*) exhibited a similar but less marked response—perhaps because stored foods were less severely depleted in this forb's large taproot. With both species, flower stalk production was the most sensitive criterion of injury. These results clearly show the importance of season: defoliations are most injurious at the time growth is well-advanced in the spring, root reserves have been expended, and substantial regrowth during the dry summer is impossible.

From a review of these and similar studies with other species, Ellison (1960) concluded that the usual effect of grazing certain species in a community is to handicap them while encouraging others. Therefore, under range conditions, the effect of selective grazing is commonly a reduction in relative amount of palatable species. Such changes in vegetation are roughly proportional to grazing intensity, being most pronounced under severe utilization. Some observations suggest that forage plants respond as well under light grazing as no grazing. However, other studies show injurious effects even at light intensities (Johnson 1956).

Despite the evidence that herbage removal is usually harmful to the plant, it has been demonstrated by research and experience that range improvement or maintenance can often be achieved by careful grazing management. Consequently, grazing sagebrush-grass range with domestic livestock can be a productive use and at the same time a means of manipulating the vegetation—for either better or worse. Since most grasses and forbs are more palatable to livestock than are shrubs, especially during the growing season, the tendency is for sagebrush and other shrubs to flourish at the expense of herbaceous species. However, properly regulated grazing can be compatible with a desirable mixture of vegetation and with other uses and values of the ranges.

Since reaction to grazing varies with composition and condition of the vegetation, intensity and season of use, kind of livestock, and husbandry practices, knowledge of these factors can be used to minimize impacts. For example, sagebrush-grass range in fair condition may be improved by a particular grazing regimen, but similar improvement of a depleted or poor condition range will probably be impossible because of the paucity of desirable herbaceous species and competition from a thick stand of sagebrush. Heavy utilization may not be particularly injurious during certain seasons when the plant is dormant or when it has adequate opportunity for regrowth, whereas lighter use at other times can be extremely injurious and override effects of favorable practices. Different kinds of livestock have different preferences for forage, and these may vary with season of grazing. Uniform livestock distribution and accompanying forage utilization can be encouraged by such simple measures as proper placement of salt, adequate watering facilities, riding or herding, and fencing—without the use of special grazing systems. As a matter of fact, the need for special systems is intensified by the failure to apply this basic husbandry.

GRAZING SYSTEMS

Driscoll (1967) described five common grazing systems, and all have been used on sagebrush-grass ranges:

1. **Continuous.**—Livestock are allowed free access to any part of a range throughout the grazing season, which may be either seasonal or yearlong. Use follows the same general pattern each year.

2. **Rotation or alternate.**—The orderly alternation, both within and between years, in the grazing use of two or more portions of the range to avoid grazing the same unit at the same time each year, but without specific regard for plant reproduction. The system is designed to promote plant vigor.

3. **Deferred.**—The delay of grazing during the growing season to promote seed production and plant reproduction, and to restore or maintain vigor of existing vegetation.

4. **Rotation-deferred.**—Rotating the deferment of two or more range units to promote plant reproduction and improve vigor. Grazing is normally allowed on all units of the range allotment for at least part of each grazing season.

5. **Rest-rotation.**—Refinement and combination of the deferred and rotation grazing systems so that complete rest will be allowed on parts of the range each year or grazing season to promote restoration of plant vigor and reproduction.

Vallentine (1979) provided a concise review of grazing systems applied to sagebrush-grass range. Pertinent information from his review and other sources is summarized in the following paragraphs.

Pechanec and Stewart (1949) recommended both rotation grazing and spring deferment for threetip and mountain big sagebrush habitat types grazed by sheep in spring and fall. They concluded that rotating grazing among different units in the spring, but in a different sequence each year, was an effective method of maintaining range in satisfactory condition or improving range in unsatisfactory condition. A further recommendation was that one unit each year be deferred until fall, and that some leeway and good judgment be used in adapting to climatically induced plant growth variations from year to year.

In southeastern Oregon on sagebrush-grass range dominated by big sagebrush, bluebunch wheatgrass, Idaho fescue, and Sandberg bluegrass, Hyder and Sawyer (1951) concluded that season-long grazing was more favorable to both cattle and vegetation, mainly because the rotation system resulted in serious overgrazing during the first period of use. On a big sagebrush-wheatgrass range in southern Wyoming, Gibbens and Fisser (1975) compared four-pasture rest-rotation, two-pasture de-

ferred, and one-pasture continuous systems grazed by cattle from spring until winter. Following a 25 percent reduction in permitted grazing at the beginning of the study, all units improved in range conditions without apparent effect on wildlife populations. Apparently stocking rates had not put enough stress on vegetation to cause differences, because range conditions improved under all treatments.

From studies with sheep in the threetip sagebrush/bluebunch wheatgrass habitat type at the U.S. Sheep Experiment Station near Dubois, Idaho, Laycock (1962) concluded that damage from heavy grazing is increased by early and continuous spring-long use and by grazing the same area during the same part of the spring season each year. He noted that grazing at the heaviest rate under spring rotation did not damage the range. Apparently, rotation grazing is necessary in the spring but not in the fall. From studies in the same vegetation type, Mueggler (1950) reported that an area in good condition was maintained over 25 years by heavy sheep grazing in the fall, whereas much lighter use in the spring caused serious deterioration (fig. 11). In a followup study, Laycock (1967) showed that both heavy fall grazing and complete protection improved poor condition range. In further studies Harniss and Wright (1982), after defining moderate grazing in the spring as 16 sheep days/acre (40 sheep days/ha), concluded that sheep can graze at the rate of about 36 sheep days/acre (90 sheep days/ha) in the summer without apparent damage to the vegetation, and that in the fall 60 sheep days/acre (150 sheep days/ha) can be grazed with a beneficial effect on the vegetation.

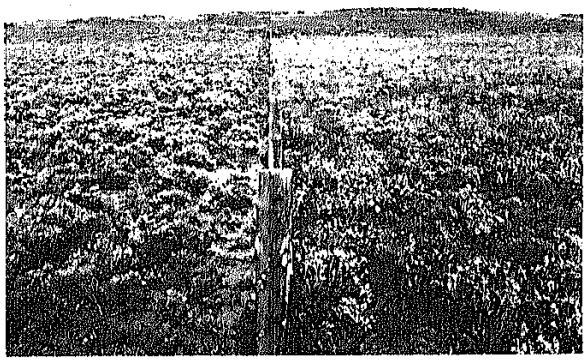


Figure 11.—Poor-condition range on the left as a result of high intensity spring grazing by sheep contrasted with excellent-condition range on the right maintained by heavy fall use. Note the difference in production of grasses and forbs. This is an *Artemisia tripartita* ssp. *tripartita/Agropyron spicatum* habitat type at the U.S. Sheep Experiment Station.

From a study on the Bighorn National Forest in Wyoming, Smith and others (1967) reported that in an Idaho fescue community with some inclusions of mountain big sagebrush, there was no evidence that rotation grazing was better than season-long grazing. They concluded that grazing intensity had more effect on animal production than did systems of grazing. In the Bighorn Basin after 8 years of different grazing treatments— including generally lighter grazing intensities and deferment in some years—range dominated by big sagebrush was largely taken over by wheatgrasses (Cooper 1953). That these striking changes occurred within so short a time suggests that the pristine vegetation of the area was grass, not shrubs, and that sagebrush was an invader whose position of dominance was maintained only as long as the grasses were suppressed by overgrazing.

On native mountain big sagebrush-grass range on the Ashley National Forest in eastern Utah, a comparison of summer-long grazing by cattle every year, summer-long in alternate years, and three-unit rest-rotation systems revealed no differences in cover, yield, or species composition of vegetation after 7 years (Laycock and Conrad 1980). Average daily gains of cattle over the entire period were similar for all systems. All areas were in fair to good condition and were grazed at a moderate intensity.

Rest-rotation grazing (Hormay and Talbot 1961), designed for management of perennial bunchgrass ranges, was originally tested at Harvey Valley in northern California on ranges that included big, low, and silver sagebrush types, as well as open grassland. After analyzing data from a five-pasture system grazed by cattle over 12 years, Ratliff and others (1972) concluded that rest-rotation grazing was superior to season-long grazing. However, Ratliff and Reppert (1974) reported that continuous grazing was more effective in controlling competing vegetation than it was damaging to Idaho fescue, and that vigor of this grass was not reduced by continuous grazing nor improved by full-season rest. From studies in the sagebrush type on the Arizona strip, Hughes (1980) concluded that rest-rotation and deferred grazing systems are a waste of money unless plant control treatments are applied to maintain an open stand of sagebrush. Grazing systems increase vigor of grasses but do not slow sagebrush reinvasion. Similarly, from observations in Nevada, Young and others (1979) reported that rest-rotation grazing is a useful system for sagebrush-grass range in fair to high condition, but for degraded ranges with overabundance of brush and little or no seed source for perennial grasses, rest-rotation as a technique for range improvement is little more than wishful thinking.

Mueggler (1972) pointed out that a problem may have been created by extending rest-rotation grazing to all types of range. Logic indicates that this grazing system has a better chance of succeeding on grasslands, where most of the vegetation is fairly palatable, than on ranges, where unpalatable species such as sagebrush and wyethia are prominent components of the stand and can take advantage of reduced competition. In any event, it seems necessary to balance desirable effects of heavy use, often associated with rest-rotation grazing, against undesirable effects on wildlife habitat, watershed protection, esthetics, and livestock weights.

Recent observations by the senior author on the BLM Pleasantview cattle allotment in southeastern Idaho indicate variable results from a three-unit rest-rotation system that has been in operation for approximately 10 years. Vegetation is largely mountain big sagebrush-grass with patches of aspen, chokecherry, or coniferous trees in canyon bottoms or on north-facing slopes. Fair-condition sagebrush-grass areas on moderate to steep slopes appear to be receiving light or moderate use and trend is upward (fig 12). This situation, which occurs on the major part of the allotment, has apparently improved general watershed conditions as banks of gullies and deeply eroded stream channels are showing substantial healing from sloughing and natural revegetation (fig 13). On the other hand, many of the more gentle slopes in the sagebrush-grass type are in poor condition with a thick stand of sagebrush and scarcely any understory of desirable grasses and forbs (fig. 14). Such areas exhibit no

Figure 12.—Fair-condition mountain big sagebrush-grass range on moderate slopes of the Pleasantview cattle allotment in southeastern Idaho. Apparently, forage utilization is not excessive and trend is upward.

Figure 13.—Apparent healing of a gully on the Pleasantview allotment as a result of bank sloughing and natural revegetation.

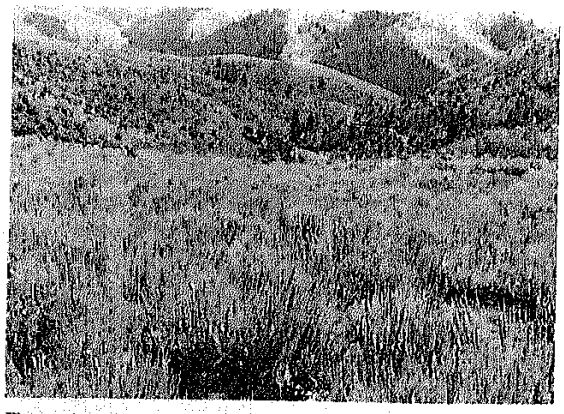


Figure 14.—Poor-condition range on a gentle slope in the Pleasantview allotment. Vegetation is a thick stand of mountain big sagebrush with an understory of annual weeds. There is no evidence of an upward trend.

Figure 15.—Depleted range within and adjacent to an aspen grove on the Pleasantview allotment. No improvement can be expected under such heavy use by cattle.

evidence of an upward trend. Likewise, other areas where cattle naturally congregate—canyon bottoms, around water developments, and aspen or chokecherry groves used for shading-up—are often in depleted or poor condition and show no evidence of improvement (fig. 15). Despite the generally satisfactory condition of much of sagebrush-grass type on the Pleasantview allotment, abuse of certain readily accessible parts of the range should not be tolerated.

Although rest-rotation grazing has been widely accepted as a panacea for range management problems, data are not available to demonstrate its real worth or to sort out the contribution of such important factors as plant control, revegetation, water development, fencing, and removal of trespass livestock—all of which have accompanied the application of rest-rotation grazing on Federal ranges. Certainly, there is no conclusive proof that rest-rotation is more effective than other systems on most sagebrush-grass ranges.

A common goal of all systems should be reduction of harmful effects of grazing while promoting beneficial effects, and many systems appear equally effective. Various combinations of rotation and deferment, as well as continuous grazing, have all proven to be successful where such factors as range condition, kind of livestock, stocking rate, season, and intensity were given proper consideration.

OTHER CONSIDERATIONS

Rate of stocking—balancing numbers of grazing animals with forage resources—is the most important part of good grazing management (Pechanec 1956). Initially, the best estimate of grazing capacity that can be made should be accomplished through one of three methods: (1) examining past stocking records and relating them to current range condition and trend; (2) determining the stocking rate that has been used on a similar range, which is now in satisfactory condition; and (3) utilizing a current range inventory. The latter, however, may provide an unreliable estimate. For the most part, ranges are by their nature too variable to allow uniform treatment or response. Furthermore, variations in kind or class of livestock, in attention given by herders or riders, in seasonal and annual plant growth, and in impacts of wildlife and range pests, all work against successful computation of grazing capacity. Consequently, actual grazing with continuing evaluation of range and livestock performance is necessary,

and precise determination of grazing capacity by other means should not be attempted.

Moderate utilization (no more than 50 percent herbage removal) of desirable forage species is necessary for adequate food synthesis and storage, maintenance of plant vigor, and completion of reproductive processes when grazing occurs during the growing season. Although heavier use may be possible when plants are dormant or if grazing is rotated, rested, or deferred to allow the forage plant to complete its life processes, such use should be applied with caution. Seemingly, there has been overoptimism in judging grazing capacity and allowable use, which has been an important factor in range deterioration. Sagebrush-grass vegetation often occurs on shallow, unstable soils, and in semiarid areas where droughts are frequent and conditions are only rarely favorable for seed production and seedling establishment. At any rate, it has become increasingly apparent that former utilization standards are often several times more than can be tolerated continuously, and that reduction in livestock numbers is often necessary to correct unsatisfactory conditions.

Range condition is especially important in the development of satisfactory management prescriptions for sagebrush-grass ranges. Depleted and poor condition ranges will respond slowly to even the best grazing management because pressure is kept on the already sparse stand of desirable grasses and forbs by grazing animals and by competition from sagebrush and other unpalatable species. Where such serious deterioration has occurred, control of unwanted species and revegetation with desirables is usually necessary. However, proper grazing practices will usually allow improvement of fair condition ranges or maintenance of those already in good or excellent condition.

Kind of livestock is another important influence. Cattle tend to graze the grasses most heavily, whereas sheep exhibit a preference for forbs. On overgrazed cattle ranges, forbs may increase initially as grasses are killed out. With continued grazing pressure, the more palatable forbs also disappear and sagebrush increases its dominance. On overgrazed sheep ranges, the palatable forbs are the first to disappear, followed by the fine bunchgrasses; sagebrush and other unpalatable shrubs take up the slack. Rotation of use between cattle and sheep can prove beneficial, especially to fair and good condition sagebrush-grass ranges.

Date at which grazing starts in the spring also can have major effects on forage and livestock production. Grazing too early may seriously damage desirable grasses and forbs that depend on stored food for growth. Early grazing can also compact the wet soil and physically damage plants, especially seedlings, and provide inadequate forage for livestock (Pechanec 1956). On sagebrush-grass ranges used by ewes and lambs, grazing can start when bluebunch wheatgrass leaves average 2.5 inches (6 cm) and soil is firm (Pechanec and Stewart 1949). This criterion, however, was established under a rotation system where sheep were only grazed for a couple of weeks before being moved to a new unit. Where grazing is continuous through the growing season, 4 to 6 inches (10 to 15 cm) initial growth may be required before the range is ready for grazing. Variations from year to year in early spring temperatures cause wide differences in date of range readiness. On the Upper Snake River Plains of Idaho over 23 years, there was a month's difference between earliest and latest dates. However, Blaisdell (1958) determined that the date of range readiness could be predicted with suitable accuracy from the mean temperature of March. The regression equation is: $Y = 65.86 - 1.39X$, in which Y is the number of days after March 31 and X is March mean temperature. In 2 out of 3 years, the actual date at which the range is ready for grazing will be within about 6 days of the date predicted.

Apparently, there are many ways to reach the desired objectives, and flexibility should not only be allowed but encouraged. Admittedly, uniformity in opening and closing the grazing season, in allowable utilization, in kind or class of livestock, in methods of salting, or in type of grazing system makes for easier administration of public rangeland, but it does not necessarily mean the best management. Early grazing can be tolerated and may be desirable if livestock are removed in time to allow adequate regrowth; heavy use can be allowed if sufficient rest is subsequently provided; change in season can be a useful management tool; and certainly no one grazing system is the best for all situations.

Good grazing management, then, is an art that requires fundamental information about the sagebrush-grass ecosystem, including characteristics and requirements of range plants and sound methods for recognizing and evaluating changes resulting from grazing use. It especially requires sensitive indicators of trend to allow early application of corrective measures, for some range abuse is apt to occur even under the best management unless discerning inspection and knowledgeable adjustments are integral parts of the system. If serious deterioration has already occurred, good management requires inexpensive and effective methods for controlling unwanted species and for establishing desirable vegetation.

most sagebrush-grass ranges and since damage from concentrated use is often severe, they must be given special consideration in the development of any range management prescriptions.

Terrestrial Wildlife and Habitat Relations

The faunal composition of any sagebrush ecosystem depends upon the kind and amount of sagebrush and associated species (McAdoo and Klebenow 1979); consequently, a habitat type classification would be a useful tool in evaluating potential for supporting wildlife. Inclusions of other vegetation types or aquatic areas are important and may be the reason for the presence of certain animals. Also, fauna may vary with the intensity of grazing by domestic livestock. A few animals such as pygmy rabbits (*Brachylagus idahoensis*), sagebrush voles (*Lagurus curtatus*), Great Basin pocket mice (*Perognathus parvus*), least chipmunks (*Eutomias minimus*), sage grouse (*Centrocercus urophasianus*), and Brewer's sparrows (*Spizello breweri*) are highly dependent upon sagebrush-grass communities. But more adaptable species occur in other habitats as well (McAdoo and Klebenow 1979), including mule deer (*Odocoileus hemionus*), pronghorn antelope (*Antilocopra americana*), bighorn sheep (*Ovis canadensis*), coyotes (*Canis latrans*), kit foxes (*Vulpes macrotes*), bobcats (*Lynx rufus*), black-tailed jackrabbits (*Lepus californicus*), and a wide variety of other rabbits, rodents, songbirds, and birds of prey.

SAGE GROUSE

Big, threetip, silver, low, and black sagebrush habitat types are important for supplying breeding, nesting, and feeding requirements of sage grouse (Rasmussen and Griner 1938; Klebenow 1969; Klebenow 1972). Because of this dependence of sage grouse on sagebrush-grass ranges, wildlife biologists have been concerned about effects of livestock grazing, plant control, and revegetation practices. Klebenow and Gray (1968) emphasized the importance of forbs in the diet of both chicks and adult birds, and cautioned that spraying for sagebrush control also destroys the forbs and creates an unsuitable environment for sage grouse, especially the juveniles.

Klebenow (1969) reported that sage grouse did not nest in, nor did broods occupy, areas of tall, dense sagebrush with little understory. He concluded that controlling such sagebrush and allowing native forbs and grasses to recover their former productivity would greatly improve the habitat for sage grouse. Apparently, fire is an ideal tool for achieving the management objective of a diverse habitat providing all the needs of sage grouse (Klebenow 1972). Since included areas of meadows and other grassy openings are also desirable for sage grouse, grass seedings for livestock range improvement can often be used to good advantage for both. Sage grouse subsist on moisture from green vegetation and from rain or dew in spring and early summer. Free water, however, is needed to satisfy requirements later in the season when forage becomes dry. Water developments should allow longer occupation of otherwise suitable sagebrush-grass range at the lower altitudes and more flexibility in its use. At any rate, good range condition for livestock appears to coincide with good habitat for sage grouse, providing sufficient sagebrush is maintained to supply their dietary needs. Sage grouse are solely dependent upon sagebrush for food from October through April of each year (Autenrieth 1980).

MULE DEER

Although somewhat scarce during early pioneer days, mule deer populations increased greatly during the second quarter of the 20th century (Julander and Low 1976). Shrubs, forbs, and grasses associated with sagebrush ecosystems are important in mule deer diets. Sagebrush-grass vegetation is especially important as winter range because of large acreage and general lack of deep snow. Sagebrush is an important part of a deer's diet in winter, whereas grasses are used primarily in the spring and forbs in the summer. Relative value of various habitat types has received only limited study. However, Tueller and Monroe (no date) observed that big and black sagebrush communities in Nevada, especially those supporting an abundance of bitterbrush, were preferred by deer.

Big sagebrush is a superior winter forage for mule deer. It is high in crude protein and coefficient of digestion (Welch and McArthur 1979a,b). Big sagebrush and curlleaf mountain mahogany are the only two winter forages of the nine reviewed by Welch and McArthur (1979a) that exceed the minimum protein requirement for wintering mule deer. The essential oils of sagebrush have been thought to inhibit digestion by mule deer rumen microflora (Nagy and others 1964). Recent work by Welch and Pederson (1981), however, indicates that the concentrations of essential oils in the rumen are too low to be inhibitory. The two scientists conclude that big sagebrush is a highly digestible winter browse. Although some other browse species are preferred to big sagebrush by wintering mule deer (Smith and Hubbard 1954), it is nevertheless highly utilized (Kufeld and others 1973) and nutritious (Welch and McArthur 1979a). Some sagebrush stands are preferred over others as browse (Hanks and others 1973; Welch and McArthur 1979a).

Because sagebrush-grass range deterioration from livestock grazing usually resulted in too much sagebrush and too little herbaceous vegetation, range restoration often involved sagebrush destruction and seeding of perennial grass. However, more recent efforts in big-game range restoration by Plummer and others (1968) have used mixtures of grasses, forbs, and shrubs for revegetation, and the result has been favorable for wildlife habitat and livestock range, as well as for other uses and values.

PRONGHORN ANTELOPE

Shrubs are the primary diet of antelope during most of the year, although forbs are important during spring and summer. Despite the prominence of sagebrush in their diets, antelope appear to do best where shrub cover is moderate and low in stature (Urness 1979). Although big sagebrush is apparently the most important species for antelope, black, low, and silver sagebrushes may be preferred in various situations and localities (Smith and others 1965). According to Beale and Scotter (1968), the general diet of antelope in Utah under good forage conditions consists mostly of succulent grass and forbs during the early spring, mostly succulent forbs during the late spring and summer, forbs and shrubs in the fall, and shrubs during the winter. As with livestock range, dense stands of big sagebrush with sparse herbaceous understories can be improved by spraying or burning followed by seeding, if necessary, to restore the forbs and grasses. Such forbs as dryland alfalfas, globemallow (*Sphaeralcea* spp.), small burnet, and Lewis flax should be especially good for antelope ranges.

The use of water by antelope is related to forage moisture (Beale and Scotter 1968). When the forage is succulent, antelope do not require any drinking water, but they drink water regularly during drought if it is available. Although antelope can survive long dry periods without drinking water, their physical condition may be impaired and subsequent winter survival may be low. During drought, does and fawns tend to restrict their grazing to areas close to available water. According to Yoakum (1979), antelope will use every kind of available water source: springs, creeks, rivers, lakes, reservoirs, and troughs fed by windmills or springs. Installation of catchments (guzzlers) on poorly watered ranges have also been successful. Such water developments are relatively maintenance-free and serve a variety of wildlife and domestic livestock. Manipulation of water availability as a means of livestock control should be discontinued (Urness 1979).

Fences to control livestock distribution can create serious problems for antelope survival. Although high death rates result from entanglement, more important are the effects of entrapment and restriction of necessary migration on survival (Yoakum 1979). Fencing, which creates better livestock distribution and alleviates concentration in stream bottoms and around ponds and seeps, also causes a dilemma for the range manager. Such activities can be of great importance to condition of wildlife and fish habitats within sagebrush-grass range areas (Urness 1979). When fence construction is deemed necessary, use of net wire should be avoided and the following specifications (Yoakum 1979) should be followed for barbed wire:

1. Bottom wire 16 inches (40 cm) from the ground, next wire up 10 inches (25 cm), third wire up another 10 inches (25 cm).
2. Bottom wire should be smooth as antelope usually go under.
3. No stays between posts.
4. Important migration routes should allow for low height or lay-down panels.
5. Fenced areas should be as large as possible so that the antelope will have maximum opportunity to obtain all basic habitat requirements.

SONGBIRDS

Alterations in songbird populations are largely related to effects of grazing and plant control on vegetation structure and composition. In Wyoming, Brewer's sparrows' use of a sprayed sagebrush stand 1 and 2 years after treatment was 67 and 99 percent lower, respectively, than use in an unsprayed stand, and no evidence of nesting was found in the sprayed stand (Schroeder and Sturges 1975). Because this species builds its nest in the shrubs, burning or mechanical removal of sagebrush would presumably have an effect similar to spraying. Populations of Brewer's and vesper sparrows (*Pooecetes gramineus*), however, were not reduced by treatments that produced only a partial kill of sagebrush (McAdoo and Klebenow 1979). Apparently, most species of songbirds in the sagebrush-grass ecosystem are dependent upon shrubs.

RABBITS AND RODENTS

A wide variety of small mammals are associated with sagebrush-grass vegetation. Pygmy rabbits depend upon sagebrush for both food and cover (Green and Flinders 1980). In southeastern Idaho, sagebrush was eaten throughout the year, although in lesser amounts in summer (51 percent of the diet) than in winter (99 percent). Grasses and forbs were eaten throughout the summer (39 and 10 percent, respectively), but greatly decreased in the diet through fall and into winter. Thick clumps of tall sagebrush are critical to their habitat. Least chipmunks are also highly dependent upon sagebrush communities (McAdoo and Klebenow 1979) and may be the most abundant rodent.

Effects of rodents on sagebrush-grass vegetation and other factors of the ecosystem are variable and not well defined. Interactions with each other, predators, and livestock are complex but may not be important in application of ordinary range management practices. However, if endangered species are involved, a more critical evaluation of interrelations will be necessary.

Riparian and Aquatic Habitat Relations

Because of the importance of riparian and aquatic inclusions as livestock range, as wildlife and fish habitat, and as recreational areas, they must be given special consideration in management plans. Livestock, especially cattle, tend to concentrate in meadows and drainages and utilize the vegetation much more closely than that on the range as a whole. Such use can have serious effects on the riparian environment by changing or reducing natural vegetation, or by actually eliminating riparian areas as a result of channel widening or degradation and lowering of the water table (Platts 1979). The most apparent effects on fish habitat are reduction of shade and cover along with increases in stream temperature, changes in stream morphology, and addition of sediment from bank sloughing and offsite soil erosion. Destruction of riparian vegetation also has serious impacts on habitat values for several terrestrial wildlife species and on recreational values associated with water, shade, desirable ground cover, and esthetics.

Extraordinary management practices will generally be necessary to protect and improve riparian and aquatic areas. Although riding and herding, rotation of use, and providing substantial periods of rest may be sufficient for some situations, others may require revegetation, reduction in livestock numbers, total exclusion of livestock by fencing, and perhaps addition of erosion control structures. In any event, these riparian and aquatic inclusions must be considered as key areas in evaluating success of management on many sagebrush-grass ranges.

monplace. Well-managed rangelands are beautiful to those who view them impartially, as well as to those who understand the concepts of land use and the long-range objectives of various management practices (USDA Forest Service 1965). Even the somewhat drab sagebrush-grass range can be interesting and perhaps beautiful when it is seen as an important watershed, a producer of livestock, or a valuable wildlife habitat.

Ranges with vigorous stands of vegetation present a constantly changing panorama. They may be a patchwork of contrasting plant communities, often with well-defined borders, or they may be single communities such as sagebrush-grass that change in appearance from season to season or even from day to night. To many people, the view is improved when it includes good livestock, vigorous vegetation, and stable soils. Enjoyment of the pastoral scene is increased by the recognition of a good job of land and livestock husbandry. Just as livestock and vegetation are vital parts of the range scene, fences, corrals, and water developments add interest and beauty if they are made to blend in with the landscape. Appearance, as well as utility, is an important factor in the design of range structures. Fences, windmills, troughs, and even corrals can be designed to harmonize with the landscape.

Wild animals of the sagebrush-grass ecosystem are also a source of interest and beauty. To some people the ultimate in outdoor enjoyment is viewing a deer or antelope in its native habitat, or a coyote slinking across an opening in the sagebrush. To others it is the sight of a gracefully soaring hawk or the song of an unseen bird. Enjoyment of wildlife, however, is heightened if it is recognized as an intrinsic part of a landscape where all living creatures are part of the biotic community.

On the other hand, a sagebrush-grass range with deteriorating vegetation and eroding soil presents an ugly picture from both esthetic and resource-management standpoints. Restoration of desirable grasses, forbs, and shrubs not only adds beauty, but also improves the livestock forage and wildlife habitat.

SUMMARY

1. Sagebrush-grass range is an important resource for production of livestock and wildlife, watershed values, and a wide variety of recreational activities.

2. Unfortunately, much of this valuable resource was depleted during early years of western settlement. Despite several decades of "improved" management, production of the sagebrush ecosystem is far below its potential. Restoration of desirable vegetation is needed.

3. The North American sagebrushes comprise subgenus *Tridentatae* (Rydb.) E. D. McArthur of the genus *Artemisia* L. Twenty taxa have been identified and described.

4. Edaphic characteristics are important in the distribution of sagebrush taxa. Although there are many exceptions, general distribution is related to soil moisture, temperature, depth, and parent material.

5. Several classification systems have been developed for sagebrush ecosystems. The habitat type concept has gained considerable acceptance by the Forest Service, whereas the range site classification system is preferred by the Soil Conservation Service and Bureau of Land Management. Both systems are based on climax vegetation, but different factors are emphasized.

6. Some 14 habitat types of dwarf sagebrush and 29 habitat types of big sagebrush have been described, but this is far from a complete treatment. Probably twice that many are in existence.

7. Because of the number involved, individual management prescriptions cannot be developed for or applied to each habitat type. Rather, general management guides are presented with necessary modifications for certain habitat types.

8. Range condition or health is the status of vegetal cover or soil in relation to a standard or ideal for a particular habitat type or site. Trend is change in condition. Reliable judgment of condition and trend is essential to effective evaluation of the success or failure of management practices.

9. Information on condition and trend of sagebrush-grass ecosystems is meager. However, general guides were developed for southern Idaho, and these can be used for a variety of habitat types and sites.

10. Condition and trend of sagebrush-grass ranges cannot be adequately evaluated without an examination of included riparian and aquatic areas, which may be particularly sensitive indicators of what is happening on the range as a whole.

11. Management objectives may be described in several ways: wise multiple use, maintenance or improvement of vegetation, or optimum sustained-yield of livestock and wildlife consistent with other uses and values. Although emphasis may vary with specific conditions or situations, it seems logical to direct primary attention to conservation of the basic resource—soil and vegetation.

12. Although stable soil is always a prerequisite to satisfactory condition, effectiveness of management is usually judged by vegetal response. Generally, a reduction in sagebrush and an increase in perennial grasses and forbs is needed.

13. Burning, spraying, and mechanical methods have all been used effectively to control sagebrush.

14. Fire is a natural phenomenon that can successfully be used to reduce sagebrush and allow increases in grasses and forbs. Big sagebrush habitat types can usually be burned, but habitat types of dwarf species may not provide enough fuel to carry a fire.

15. Response of mountain big sagebrush and associated species was studied on a prescribed burn in southeastern Idaho for 30 years. With few exceptions, production of grasses and forbs decreased the year after burning, but recovery was rapid, especially by rhizomatous species. Sagebrush was practically eliminated and its reestablishment from seed was very slow, whereas rabbitbrush and horsebrush sprouted profusely and quickly regained their original size. However, after increasing during the first 12 years following burning, nearly all species of grasses, forbs, and shrubs decreased during the next 18 years as sagebrush regained dominance.

16. Response of individual plants to fire is highly variable. However, if initial effects that are generally injurious to all species are ignored, then the following classification is fairly reliable: (a) **severely damaged**—shrubs that are unable to sprout, suffrutescent forbs, and fine bunchgrasses with densely clustered culms such as Idaho fescue; (b) **only slightly affected**—coarse bunchgrasses, fine bunchgrasses with loosely clustered culms such as bluegrass, forbs that are neither suffrutescent nor rhizomatous, and shrubs with a limited sprouting habitat; and (c) **considerably benefited**—shrubs with a strong sprouting habit, rhizomatous grasses, and rhizomatous forbs.

17. Since vegetal response is closely related to burn intensity, winter or early spring burns will be less injurious to most species than those in summer or fall when soil moisture is low and temperatures are high.

18. Nutrients contained in vegetation are released by fire in the form of volatiles (nitrogen and sulfur) or ash (phosphorus,

potassium, calcium, magnesium). The former are at least partially lost to the system, but the latter generally are added to the soil.

19. For the most part, burning can be reliably prescribed only for habitat types of threetip sagebrush and basin, Wyoming, and mountain big sagebrushes.

20. Burning as a range improvement measure should be implemented only after alternatives have been considered and a satisfactory plan has been developed and approved. Where, when, and how to burn should all be addressed, as well as followup management.

21. Since effective control of big, low, black, silver, threetip, and alkali sagebrushes with 2,4-D has been reported, it is assumed that all sagebrushes are susceptible to this chemical, especially in the spring when the plants are actively growing.

22. Because of the effects of 2,4-D on species associated with sagebrush, composition of the vegetation must be carefully considered. Since perennial grasses are seldom damaged, they can be expected to increase as a result of reduced competition from sagebrush. However, many perennial forbs and shrubs are severely damaged by spraying, and this probable damage to desirable species must be evaluated in relation to anticipated benefits.

23. Several mechanical methods for sagebrush control have been used successfully since the 1930's, including plowing or disking, root cutting, beating or shredding, railing, and chaining. Choice of method depends upon such factors as size and density of sagebrush, need to destroy or preserve understory vegetation, size of area to be treated, rockiness and other characteristics of the site, and availability of equipment.

24. Insects, small mammals, and large herbivores are all possibilities for regulated biological control of sagebrush. However, only grazing of sheep during the late fall or winter has shown significant promise to date.

25. Control measures apparently do not have serious long-term impacts on either vegetation or soil. If necessary, sagebrush control at 20-year intervals should be tolerable for most situations.

26. On sagebrush-grass ranges that have been depleted by past abuses, neither complete protection nor conservative grazing can restore a desirable vegetal cover within a reasonable time. Consequently, removal of competing vegetation, especially sagebrush, and seeding with desirable grasses, forbs, and shrubs is the only satisfactory method of restoration.

27. Since early efforts in sagebrush-grass range revegetation were aimed at increasing livestock forage, establishment of a good stand of perennial grass was the usual objective. With the recognition of the limited value of single species, more and more attention was given to mixtures that would improve multiple-use values.

28. In recent years, increasing emphasis has been placed on the use of shrubs in revegetation mixtures. Studies have demonstrated that a number of native and exotic shrubs can be successfully established within most sagebrush-grass communities.

29. Guides developed by Plummer and others (1968) for big-game ranges are generally appropriate for revegetation of sagebrush-grass ranges: changes in plant cover must be deemed necessary; terrain and soil must be suitable for selected restoration; precipitation must be adequate; competition from existing vegetation must be minimal; only adapted species and strains should be planted; mixtures should be generally used; sufficient good quality seed should be planted; seed must be covered; planting should be done in the season that promises the best environment; and revegetated areas must be properly managed.

30. Although the influence of grazing may be exerted in many ways, the most obvious is reduction in volume of herbage and area of photosynthetic surface. Defoliation of herbaceous species is most injurious at the time growth is well advanced in the spring, root reserves have been expended, and substantial regrowth during the dry summer is impossible.

31. Since most grasses and forbs are more palatable to livestock than are shrubs, especially during the growing season, the tendency is for sagebrush and other shrubs to flourish at the expense of herbaceous species. However, properly regulated grazing can be compatible with a desirable mixture of vegetation.

32. Five common grazing systems have been described, and all have been used on sagebrush-grass ranges: continuous, rotation or alternate, deferred, rotation-deferred, and rest-rotation.

33. A common goal of all systems should be reduction of damage from grazing while promoting beneficial effects, and many systems appear equally effective. Various combinations of rotation and deferment, as well as continuous grazing, have all proven to be successful where such factors as range condition, kind of livestock, stocking rate, season, and intensity were given proper consideration.

34. Although rest-rotation has been widely accepted as a panacea for range management problems, data are not available to demonstrate its real worth or to sort out the contribution of such important factors as plant control, revegetation, water development, fencing, and removal of trespass livestock—all of which have accompanied the application of rest-rotation grazing on Federal ranges. Certainly, no conclusive proof exists that rest-rotation is more effective than other systems on sagebrush-grass ranges.

35. Rate of stocking—balancing numbers of grazing animals with forage resources—is the most important part of good grazing management. Although grazing capacity can be estimated, actual grazing with continuing evaluation of range and livestock performance is necessary, and precise determination of grazing capacity by other means should not be attempted.

36. Range condition is especially important in the development of satisfactory management prescriptions. Depleted and poor condition ranges will respond slowly to even the best grazing management because pressure is kept on the already sparse stand of desirable grasses and forbs by grazing animals and by competition from sagebrush and other unpalatable species.

37. Kind of livestock is another important influence, and rotation of use between cattle and sheep can be beneficial, especially to fair and good condition sagebrush-grass ranges.

38. Good grazing management is an art that requires fundamental information about the sagebrush-grass ecosystem, including characteristics and requirements of range plants and sound methods for recognizing and evaluating changes. It especially requires sensitive indicators of trend to allow early application of corrective measures, for some range abuse is apt to occur even under the best management unless discerning inspection and knowledgeable adjustments are integral parts of the system.

39. Although past use of sagebrush-grass range has centered around livestock production, more and more recognition has been given in recent years to other uses and values. Vegetation manipulation through livestock grazing, plant control, and revegetation can greatly influence habitat quality and wildlife populations.

40. Inclusions of aquatic and riparian habitat, meadows, patches of trees, and so forth, have benefits to wildlife far out of proportion to the small area they occupy. They deserve extraordinary management and must be considered as key areas in evaluating effectiveness.

41. Deteriorating vegetation and eroding soil present an ugly picture from both esthetic and resource management standpoints, but even the somewhat drab sagebrush-grass range can be interesting and beautiful when seen as an important watershed, a producer of livestock, or a valuable wildlife habitat.

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APPENDIX

KEY TO THE TAXA OF ARTEMISIA (From Beetle 1960)

Head composed of both 2-lipped ray flowers and regular disk flowers; vegetative branches with leaves shallowly and sharply 3-toothed

1. *A. bigelovii*

Head composed only of 5-toothed disk flowers; leaves of vegetative branches entire or lobed; if lobed, usually not both sharply and shallowly

Dwarf desert cushion half-shrubs about 1 dm. tall; leaves pinnatifid into 3-11 linear-subulate divisions, green; outer involucral bracts linear to lanceolate, nearly glabrous

2. *A. pygmaea*

Taller shrubs; leaves entire or toothed at the apex, or, if dissected into linear divisions, then canescent; outer involucral bracts orbicular or ovate, sometimes narrowed to an herbaceous tip, usually densely pubescent

Plants erect, crown spreading above the base, the older branches rigid, at least the first fascicle leaves cuneate, at least the first leaves lobed; or sometimes deeply so; dying after burning; subtending leafy bracts of the inflorescence shorter than the heads

Dwarf plants (1-3 dm. tall) with small leaves mostly less than 1 cm. long; leaves flabelliform; inflorescence dark brown and very persistent the year following seed shedding; involucre very narrowly campanulate

3. *A. nova*

Erect plants (except that dwarf forms are common in A. *tridentata* and *A. arbuscula*), usually more than 3 dm. tall, commonly much higher; most leaves more than one cm. long, old inflorescence stalks gray and weakly persistent; involucre campanulate to broadly campanulate

Involucres narrowly campanulate, heads few-flowered, often in open panicles; leaves narrowly cuneate, not layering

Leaves short, branches flexuous; narrowly racemose paniculate

Most leaves coarse, cuneate

4. *A. arbuscula* subsp. *arbuscula*

All leaves fine, deeply trifid

5. *A. arbuscula* subsp. *thermopola*

Leaves elongate, branches stiff; openly paniculate

Inflorescence branches erect; achene glabrous

6. *A. tridentata* subsp. *tridentata*

Inflorescence branches recurved; achene often hairy

7. *A. tridentata* subsp. *tridentata* forma *parishii*

Involucres broadly campanulate; heads many-flowered; leaves broadly cuneate; often layering

Late maturing (seed ripe in October); leaves usually truncate, merely toothed, or occasionally acutely lobed

Heads 3-4 mm. broad; leaves not unusually large, often very much reduced

8. *A. tridentata* subsp. *vaseyana*

Heads 4-5 mm. broad; leaves unusually large, at times 6.5 cm. long, and 2 cm. broad

9. *A. tridentata* subsp. *vaseyana* f. *spiciformis*

Early maturing (seed ripe by the end of August), at least the first leaves (which subtend the fascicle leaves) deeply lobed; lobes of all the leaves obtuse or rounded

10. *A. longiloba*

Plants dwarf or prostrate spreading, the older branches flexuous, most leaves entire, pointed, cleft or deeply lobed (*A. cana* is often erect but has simple, or irregularly lobed, pointed leaves; *A. tripartita* subsp. *tripartita* is often erect but has deeply divided to very narrowly linear leaves; *A. rigida* likewise may be erect but never has truncate cuneate leaves); although evidence is lacking in some cases apparently either stump-sprouting, layering, or spreading from underground rootstocks after burning; subtending leafy bracts of the inflorescence longer than the heads

Heads commonly 4-6 mm. broad; leaves simple, cuneate, lanceolate, or sometimes deeply lobed

Leaves persistent, deeply notched with rounded lobes; inflorescence an elongate spike of few often darkly purplish heads; young stems green

11. *A. rothrockii*

Leaves deciduous in cold winters; simple and entire, or with acute lobes; inflorescence paniculate, heads green; young stems white

Leaves broadly lanceolate, simple, mostly over 2 cm. long

12. *A. cana* subsp. *cana*

Leaves narrowly lanceolate, simple to deeply divided with asymetrical, acute lobes, canescent to green; mostly under 2 cm. long

Leaves weakly canescent to green; plants along mountain streams

13. *A. cana* subsp. *viscidula*

Leaves silvery canescent, the pubescence loose; plants of poorly drained or alkaline soils

14. *A.* cana subsp. *bolanderi*

Heads commonly 2-4 mm. broad; leaves divided into 3-5 linear, obtuse lobes

Inflorescence an elongate spike, the subtending bracts of equal length to the tip

15. *A. rigida*

Inflorescence an open or racemose panicle, the subtending bracts smaller toward the tip

Leaves up to 3 cm. long, at most the lobes 1 mm. broad

Plants tall (up to 2 meters); leaves seldom over 2 cm. long, the lobes 0.50 to 0.75 mm. wide

16. *A. tripartita* subsp. *tripartita*

Plants dwarf (rarely over 1.5 dm. tall); leaves often 3 cm. long, the lobes 1 mm. wide

17. *A. tripartita* subsp. *rupicola*

Leaves up to 4 cm. long, each lobe 2-3 mm. broad

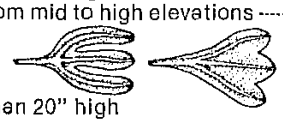
18. *A. argillosa*

KEY TO *ARTEMISIA* (SECTION TRIDENTATAE) IN OREGON
(from Winward 1980)

1a Leaves entire[1]

2a Leaves silver-gray, plants from internally drained basins with seasonal flooding ---------- *A. cana ssp. bolanderi*

2b Leaves green-gray, plants along stream bottoms or meadow margins from mid to high elevations ---------- *A. cana ssp. viscidula*

1b Leaves divided or lobed 

3a Mature[2] shrubs less than 20" high

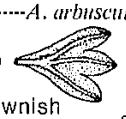
4a Leaves divided (lobe length > 3 times width)

5a Flower stalk leaves divided, inflorescence spicate, all leaves winter deciduous ---------- ---------- *A. rigida*

5b Flower stalk leaves entire

6a Inflorescence paniculate, upper flower stalk leaves much longer than flower heads ---------- *A. tripartita ssp. tripartita*

6b Inflorescence spicate or racemose, flower stalk leaves equal or only slightly longer than flower head ---------- *A. arbuscula ssp. thermopola*

4b Leaves lobed (lobed length < 3 times width) 

7a Inflorescence paniculate, seed stalks brownish and persist into following year ---------- ---------- *A. nova*

7b Inflorescence spicate or racemose, seed stalks grayish and weakly persistent

8a Seeds mature mid-July to mid-August ---------- *A. longiloba*

8b Seeds mature late August to October ---------- *A. arbuscula ssp. arbuscula*

3b Mature shrubs taller than 20"

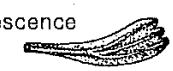
9a Uneven topped shrubs, flower stalks arise throughout crown

10a Mature plants > 40" in height, leaf margins straight ---------- *A. tridentata ssp. tridentata*

10b Mature plants < 40" in height, leaf margins belled outward ---------- *A. tridentata ssp. wyomingensis*

9b Even topped shrubs, flower stalks arise from upper crown and extend above foliage

11a Leaf margins belled outward, inflorescence spicate or racemose ---------- *A. arbuscula ssp. arbuscula*

11b Leaf margins straight, inflorescence paniculate 

12a Four to six flowers per head ---------- *A. tridentata ssp. vaseyana*

12b More than six flowers per head, plant often layering ---------- *A. tridentata form spiciformis*

[1] Key based on persistent (overwintering) leaves unless otherwise noted.

[2] Mature infers at least 20 years old (see xylem layers).

TAXONOMIC KEY AND DESCRIPTIONS
(from Winward and Tisdale 1977)

Three important features of the big sagebrush group must be recognized for identification purposes:

1. Leaves from the flowering branches are not always reliable for taxonomic separation.
2. Leaves of the vegetative shoots are of two types, ephemeral or persistent. Ephemeral leaves are larger and often irregularly lobed. They are among the earliest to develop, and are shed as the season advances. Persistent leaves are typically 3-lobed, and over-winter on all big sagebrush taxa. Differences between ephemeral and persistent leaves, and leaf variation among taxa of big sagebrush are shown in Fig. *a*.
3. Leaf and growth form characteristics are most easily distinguished after plants have flowered.

The following key is designed for separations based on persistent leaves only. Additional characteristics are provided under the individual plant descriptions. Illustrations of some characters used in the key are presented in Fig. *b*.

Artemisia Tridentata Key

1 Uneven topped shrubs, flower stalks arising throughout the crown

2 Mature plants usually more than 100 cm (40 inches) in height, leaf margins straight

3 Leaves relatively long-narrow, L/W ratio 4.0 or greater, fluoresces reddish brown in alcohol (See Winward and Tisdale 1969.)

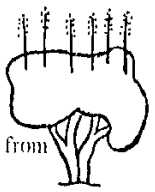
A. tridentata subspecies *tridentata*

3 Leaves relatively long-broad, L/W ratio less than 4.0, fluoresces bluish-cream in alcohol

A. tridentata "X"

2 Mature plants less than 100 cm (40 inches) in height, leaf margins curved outward, fluoresces reddish brown in alcohol

A. tridentata subspecies *wyomingensis*



1 Even-topped shrubs, flower stalks arising from upper crown and extending above foliage

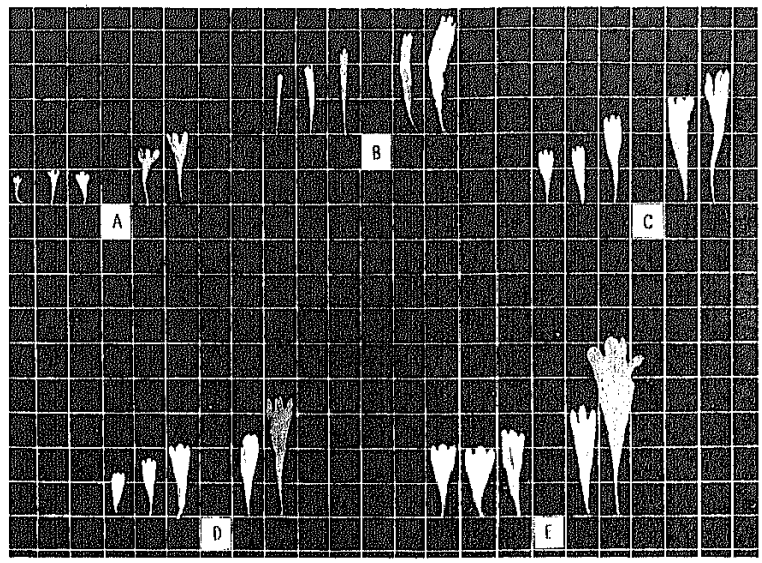
4 Flower heads less than 1.5 mm wide, 4-6 flowers per head, plants not layered, fluoresces bluish-cream in alcohol

A. tridentata subspecies *vaseyana*

4 Flower heads more than 1.5 mm wide, more than 6 flowers per head, plants often layered, fluoresces bluish-cream in alcohol

A. tridentata subspecies *vaseyana* form *spiciformis*

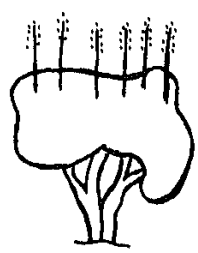
A subspecies *wyomingensis*
B subspecies *tridentata*
C subspecies *vaseyana*
D "X"
E form *spiciformis*



Note: The three leaves on the left of each group are persistent, and the two in the right of each group are ephemeral. The background is lined into 0.5 cm squares.

Fig. a. Shapes and sizes of representative leaves of five big sagebrush taxa.

even topped shrubs
(flower stalks from upper crown area only)



uneven topped shrubs
(flower stalks throughout crown)

leaf margins curved outward (bell shape)

leaf margins straight (wedge shape)

leaves widest at lobe tips

leaves widest just below lobes

Fig. b. Diagramatic sketch of important morphological characteristics used in the taxonomic key of *Artemisia tridentata*.

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This paper is a distillation of some of the most important information resulting from a half-century of research on sagebrush-grass rangelands. It has been prepared as a reference for managers and users of rangelands and as a help for planning and decisionmaking.

KEYWORDS: range management, range improvement, sagebrush-grass ranges, sagebrush ecology, sagebrush taxonomy

PESTICIDE PRECAUTIONARY STATEMENT

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

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